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# THE ASTROPHYSICAL JOURNAL

JUL 11 1932

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

*Edited by*

GEORGE E. HALE
Mount Wilson Observatory of the Carnegie Institution of Washington

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## JUNE 1932

ON THE ABSORPTION BAND AT λ 6191 IN THE SPECTRUM OE JUPITER — *C. T. Elvey and Arthur S. Fairley* 373

LINES OF TUNGSTEN AND RHENIUM APPEARING IN THE SPECTRUM OF THE ELECTRIC FURNACE - - - - - - - - - - - *Arthur S. King* 379

EVIDENCE FOR SPACE REDDENING FROM BRIGHT B STARS - *Emma T. R. Williams* 386

SPECTRAL ENERGY-DISTRIBUTION OF THE HIGH-CURRENT VACUUM TUBE — *J. A. Anderson* 394

ON THE VARIABLE LINES OF HELIUM AND MAGNESIUM IN THE SPECTRUM OF 13 μ SAGITTARII - - - - - - - - - - - - - *W. W. Morgan* 407

THE SPECTRUM OF B.D.+11°4673 DURING THE YEARS 1929–1931 - *Paul W. Merrill* 413

MINOR CONTRIBUTIONS AND NOTES

NOTE ON THE SPECTRUM OF 37 θ AURIGAE - - - - - - - *W. W. Morgan* 423

DETECTION OF THE GEGENSCHEIN WITH A PHOTO-ELECTRIC PHOTOMETER — *C. T. Elvey* 424

ERRATA - - - - - - - - - - - - - - - - - - - - - - 427

INDEX - - - - - - - - - - - - - - - - - - - - - - - 428

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THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME LXXV JUNE 1932 NUMBER 5

# ON THE ABSORPTION BAND AT λ 6191 IN THE SPECTRUM OF JUPITER

By C. T. ELVEY and ARTHUR S. FAIRLEY

ABSTRACT

A photometric study of the absorption band in the spectrum of Jupiter at λ 6191 and of the red absorption bands of water show that the identification by McLennan, Ruedy, and Burton of the bands of the major planets with those of water is not possible. Also, observations show that the intensity of the band does not increase at the limb of the planet. A contour of the band is given.

The absorption spectrum of water has been studied by J. C. McLennan, R. Ruedy, and A. C. Burton,[1] and they have "concluded that the absorptions in the red region common to the four major planets can be attributed to water, not as vapour or as ice, but in the liquid state." As it appears somewhat doubtful that the explanation of the bands is due to absorption by water since they increase in intensity with the more distant planets (the colder ones), it seemed desirable to make an observational test of the identification by a comparison of the contour of the absorption band in the spectrum of the planets with that of water. A number of spectrograms of Jupiter covering the red region were made with the auto-collimating spectrograph attached to the 40-inch telescope of the Yerkes Observatory on November 26, 1928. On the same night a spectrum of the moon was taken for comparison, and on previous days the spectrum of the sun was obtained also for determining the spectral sensitivity of the photographic plate, Ilford rapid process panchromatic.

[1] *Proceedings of the Royal Society of London*, A, **120**, 296, 1928.

This particular brand of plates has a hump in the sensitivity-curve just to the red of the absorption band we were investigating and so the spectrum of sunlight had to be used in order to delineate the continuous background.

D. H. Menzell[1] has suggested that the bands in the spectra of the major planets may be due to molecules which dissociate at very low temperatures, since the intensities of the bands increase with the distance of the object from the sun. Also, he[2] has reported that the intensities of the bands are stronger at the limbs of the planets than at the center, which he also attributed to lower temperatures. In another note he[3] shows on theoretical grounds that the identification of the absorption bands in the spectra of the planets with those of water is very improbable.

The spectrograms of the planet Jupiter were obtained by placing the slit of the spectrograph across the disk of the planet, and since the scale of the 40-inch telescope is 10″ per millimeter, a single spectrogram serves to study different parts of the disk. Most of the spectrograms were obtained with the slit across the center of the disk, which places it at an angle with the "belts" of Jupiter since the slit is parallel with the celestial equator. Spectrograms were taken also with the center of the slit at about 40° north and south of the center of the planet.

All spectrograms were calibrated with a tube sensitometer through a red filter (Wratten No. 29) and developed for 5 minutes in D-11. The spectrograms were analyzed with the registering microphotometer, each plate being run through the instrument to give a record from the D lines to the red limit of the spectrogram. The reduction consisted in determining differences of intensity between the continuous spectrum at the D lines and points at 5-mm intervals on the tracing toward the red. It was not possible to trace the continuous spectrum across the absorption band as is usually done for stellar absorption lines since the plate used had a hump in its sensitivity-curve just to the red of the band. This necessitated finding the value of the continuous background from spectrograms of the moon and the sun. Since the intensity-curve of the spectrum to the red of the

[1] *Popular Astronomy*, **32**, 225, 1924. [2] *Ibid.*, **35**, 489, 1927.

[3] *Publications of the Astronomical Society of the Pacific*, **42**, 228, 1930.

D lines is expressed in stellar magnitudes, it is necessary only to take the difference to find the amount of absorption in Jupiter's atmosphere. The resulting curves are shown in Figure 1, lower diagram, in which the intensity-curve of the solar spectrum is represented by the circles (since the solar and lunar spectra were in good agreement

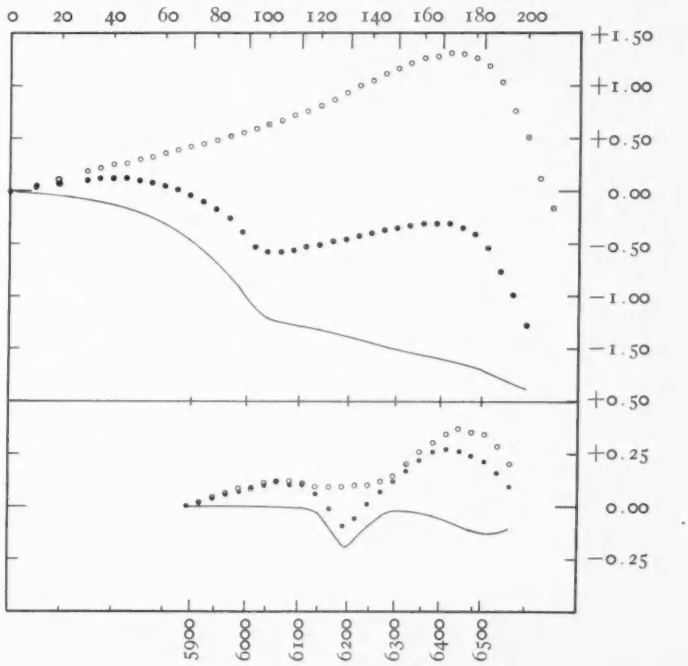



FIG. 1.—Spectral intensity curves. The ordinates are intensities in stellar magnitudes and the abscissae are wave-lengths. Upper diagram: Circles represent the spectrum of the lamp; dots, the spectrum of the lamp through 6.5 m of water; and the curve is the absorption of the water. Lower diagram: Circles represent the spectrum of the sun's light; dots, the spectrum of Jupiter; and the curve is the absorption by Jupiter's atmosphere showing the absorption band λ 6191.

the two were averaged) and the spectrum of Jupiter by the dots. The solid line is the difference and shows the amount of the absorption. The ordinates are expressed in magnitudes and abscissae are in angstrom units. It will be seen that toward the blue from the band the two curves are essentially parallel. The contour of the absorption band expressed in percentages of absorption is plotted in Figure 2. It will be seen that the band with the center at λ 6191

is essentially symmetrical and that the band at λ 6460 is making its appearance. The band is about 200 A wide at 1 per cent absorption. The central intensity is 17 per cent of absorption and the total absorption expressed as angstroms of complete absorption is 15.9 A. R. Wildt and E. I. Meyer[1] give the central depth of the band λ 6191 as 0.30 mag., or 25 per cent of absorption.

Each spectrogram was made with the slit across the disk of the planet and thus gave spectra of both limbs and the center at the same time. The centers and edges of the spectra were photometered and no increase in the intensity of the band at the limb, as reported

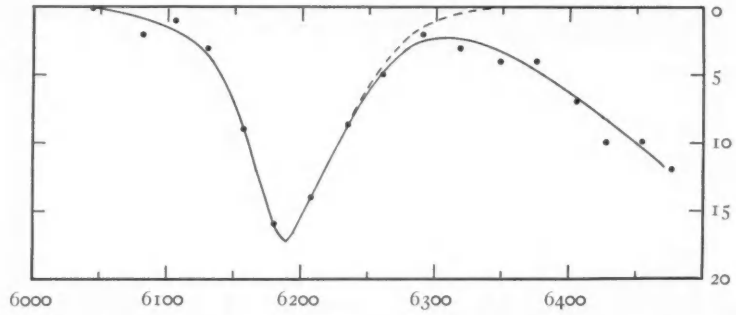



FIG. 2.—Contour of λ 6191 in the spectrum of Jupiter. The ordinates are percentages of absorption.

by Menzell, was found, all the curves agreeing well within the errors of observation. The mean deviation of the observations (12 curves) for a point near the center of the band is ±3 per cent of absorption, and most of this is due to two plates of high density. The error is ±1 per cent of absorption if these two plates are left out.

Since our spectrograms of Jupiter did not indicate that the absorption bands had an appearance similar to those of water as illustrated by McLennan, Ruedy, and Burton, we decided to obtain the absorption spectrum of water on calibrated plates. A pipe about 6.5 m long was set up with the spectrograph at one end and a projection lantern at the other for a source of light. Spectra were photographed with the pipe empty and with it filled with distilled water. For these spectrograms we used the new Wratten and Wainwright hypersensitive panchromatic plate, which has a more uniform spec-

[1] *Zeitschrift für Astrophysik*, **3**, 354, 1931.

tral sensitivity-curve in the red region. A comparison spectrum of neon was photographed on each plate. Microphotometric tracings of a pair of spectra are shown in Figure 3, the neon lines showing as peaks on the curves. It will be seen from the curves that toward the green region the spectra with and without the water are essentially parallel and that the absorption begins gradually in the yellow region

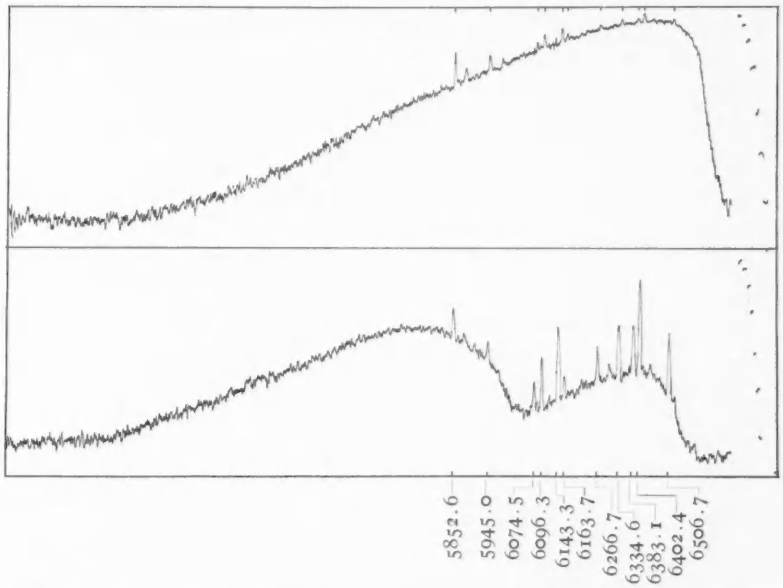



FIG. 3.—Microphotometric tracings of the spectrum of a Mazda lamp with and without an absorbing column of water. The peaks on the curves are from the superimposed spectrum of Neon.

and continues on through the red. There is the appearance of a band at about λ 6100, but this is merely an effect of the combined sensitivity of the plate and the emission of the lamp. When the curves are reduced similarly to those for Jupiter but obtaining intensities relative to a point of shorter wave-length, it is seen that the band is only apparent. The upper diagrams of Figure 1 are the spectral intensity-curves. The circles represent the spectrum of the lamp without the water in the path and the dots the spectrum of the lamp with the absorption of water. The difference of the two curves is shown by the continuous line and represents the absorption of water

relative to the point in the green region. The absorption is expressed in stellar magnitudes. An examination of this curve and the one for Jupiter shows no similarity in the two absorptions.

In conclusion we can say from the observational point of view that the band λ 6191 in the spectrum of Jupiter, or the other major planets, cannot be due to absorption by water; furthermore, that the intensity of the absorption band in Jupiter does not increase toward the limb of the planet.

YERKES OBSERVATORY
February 3, 1932

# LINES OF TUNGSTEN AND RHENIUM APPEARING IN THE SPECTRUM OF THE ELECTRIC FURNACE[1]

By ARTHUR S. KING

ABSTRACT

Metallic tungsten and rhenium were fused in the carbon-tube furnace, and the vaporization of the resulting carbides at temperatures near 2800° C gave spectra consisting of the low-level lines of each element. The lines listed, whose presence in the furnace is at least probable, number 75 for tungsten and 19 for rhenium in the spectral range λλ 2800–6700. The rhenium furnace lines, all from the first three levels assigned by W. F. Meggers, show hyperfine structure in a variety of patterns.

Tungsten and rhenium, with melting-points near 3400° and 3150° C, respectively, are the most refractory of the metals, and their vaporization for spectroscopic examination would seem beyond the range of the carbon-tube furnace, which in its present form may be operated satisfactorily up to about 3000° C. The formation in each case of a carbide of much lower melting-point, by a combination of the metal with the material of the furnace tube, has, however, permitted the vaporization of both tungsten and rhenium and the excitation of their more sensitive spectral lines.

The number of furnace lines observed for these elements is a small percentage of the neutral lines emitted by the arc and is in contrast with the general effectiveness of the furnace, which in some cases brings out the neutral spectra better than the arc. This limitation is not necessarily a result of the difficult vaporization of tungsten and rhenium, but rather a consequence of the fact that relatively few of their lines come from the lower atomic energy-levels. The data obtained do not suffice for a temperature classification of the spectra, but merely for a selection of the low-level lines, since, in spite of the high furnace temperatures employed, the spectra obtained consist of the "low-temperature" lines of these elements. The furnace lines observed are in general strong in the arc, but the usual selective action is found, as many strong arc lines, presumably of high level, are absent from the furnace.

*Tungsten.*—In charging the furnace with tungsten, two or three 1-mm rods, each about 10 cm long, were laid side by side in the

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington,* No. 448.

central part of the graphite tube. As the conditions were especially favorable for close observation, the steps in the fusion of the metal will be described. A Leeds and Northrup pyrometer was directed at the interior of the tube, slightly off the axis, thus permitting temperature measurements of the wall while the rods were clearly visible in the field of the instrument. As the temperature was raised slowly, action on the surface of the rods appeared to begin at about 2300° C. Although the rods still retained their round form, carbonization was presumably under way, since the formation of carbon vapor, as indicated by bands in the spectrum, begins at about 2000°. The altered appearance of the tungsten continued up to 2450°, when the rods fused together. Readings of the temperature at which fusion occurred agreed closely for different charges of the furnace. At approximately 2600°, with some ebullition taking place, the molten metal formed globules. At a temperature about 100° higher, the globules collapsed along the tube, and the molten material sank into the graphite. The exposures for the spectrum were then made at various temperatures up to 3000° C. When the tube was broken apart after a run, the blue-green tungsten carbide was found in a trough along the tube, having eaten its way half through the 3-mm wall.

Table I includes those lines of tungsten that are clearly present in the furnace spectrum and a few others that are very strong in the arc spectrum but are masked on furnace spectrograms by lines belonging either to the Swan bands of carbon or to the cyanogen bands. Through the use of the second-order spectrum to λ 5500, the band structure was rendered fairly open, and the presence in the furnace or absence from it of most of the stronger arc lines was evident enough. No tungsten lines could be identified with certainty in the furnace spectrum to the red of λ 5500, although the examination was continued to λ 6700. Only a few arc lines in this region are strong enough, however, to be expected in the furnace. As some of these coincide with strong lines of the carbon bands, their presence was quite uncertain. Since none of the lines which are faint in the arc appeared among the numerous furnace lines occurring in the region of short wave-length, the low-level lines of tungsten are probably limited to those which are strong in the arc. The ultimate lines,

TABLE I

TUNGSTEN LINES IN FURNACE SPECTRUM

| λ (BELKE) | INTENSITY | | NOTES |
|---|---|---|---|
| | Arc | Furnace | |
| 2831.387 | 100 | 4 | |
| 2848.029 | 60 | 2 | |
| 2856.033 | 40 | 1 | |
| 2866.071 | 25 | 1— | |
| 2879.110 | 30 | 1 | |
| 2879.400 | 30 | 3 | |
| 2896.445 | 125 | 4 | |
| 2918.253 | 20 | 1 | |
| 2934.994 | 40 | 2 | |
| 2944.410 | 200 | 10 | |
| 2946.992 | 200 | 8 | |
| 2964.520 | 40 | 2 | |
| 2979.860 | 50 | 3 | |
| 3017.447 | 60 | 4 | |
| 3024.931 | 50 | 4 | |
| 3041.876 | 25 | 2 | |
| 3043.819 | 40 | 1 | |
| 3046.452 | 50 | 3 | |
| 3049.694 | 60 | 5 | |
| 3073.287 | 20 | 1—? | Presence in furnace uncertain |
| 3093.515 | 40 | 1 | |
| 3108.019 | 30 | 1 | |
| 3119.773 | 15 | 2 | |
| 3120.188 | 30 | 1 | Measured by writer; furnace line is red component of arc doublet |
| 3155.095 | 8 | 1 | |
| 3176.600 | 30 | 2 | Measured by writer; furnace line is red component of arc doublet |
| 3191.577 | 60 | 3 | |
| 3198.843 | 60 | 1 | |
| 3207.248 | 80 | 2 | |
| 3208.279 | 50 | 1 | |
| 3215.558 | 150 | 5 | Measured by writer; furnace line is violet component of arc doublet; ultimate line |
| 3242.026 | 30 | 1 | |
| 3281.944 | 50 | 1— | |
| 3300.819 | 150 | 5 | |
| 3311.389 | 100 | 5 | |
| 3326.194 | 60 | 1? | Presence in furnace uncertain |
| 3331.678 | 100 | 3 | |
| 3354.451 | 30 | 1? | Presence in furnace uncertain |
| 3373.756 | 60 | 2 | |
| 3398.099 | 20 | 2 | |
| 3545.234 | 8 | 2 | |
| 3590.830 | 30 | 1 | |
| 3617.522 | 800 | 10 | |
| 3707.929 | 300 | 1? | Presence in furnace uncertain |
| 3768.448 | 200 | 2 | |

TABLE I—*Continued*

| λ (Belke) | Intensity | | Notes |
|---|---|---|---|
| | Arc | Furnace | |
| 3780.770 | 300 | 3 | |
| 3847.501 | 50 | 1? | May be band line |
| 3867.986 | 300 | 4 | In band structure; probably present in furnace |
| 3881.402 | 100 | ? | Concealed by band |
| 3983.294 | 60 | 1? | May be band line |
| 4008.769 | 1000 | 10 | Ultimate line |
| 4045.615 | 100 | 1? | May be band line |
| 4074.374 | 500 | 5 | |
| 4102.713 | 150 | 1? | May be band line |
| 4244.374 | 200 | 1? | Presence in furnace uncertain |
| 4269.399 | 300 | 2 | |
| 4294.623 | 1000 | 15 | Ultimate line |
| 4302.123 | 500 | 4 | Ultimate line |
| 4484.197 | 200 | 2 | |
| 4570.665 | 60 | ? | Concealed by band |
| 4680.539 | 400 | ? | In band structure; faint if present in furnace |
| 4693.748 | 100 | ? | Coincides with strong band line |
| 4757.565 | 200 | 1 | |
| 4843.829 | 500 | 8 | |
| 4886.922 | 400 | 5? | Blend band line |
| 4982.613 | 200 | 3 | |
| 5006.169 | 400 | ? | Blend band line |
| 5015.334 | 300 | ? | Blend band line |
| 5053.300 | 500 | 3 | |
| 5054.615 | 100 | ? | Blend band line |
| 5069.148 | 100 | 1? | May be band line |
| 5224.680 | 400 | 3 | |
| 5492.331 | 100 | ? | Concealed by band |
| 5514.712 | 500 | ? | Concealed by band |
| 5631.970 | 80 | ? | Concealed by band |

λλ 3215.6, 4008.8, 4294.6, and 4302.1, are among the strongest furnace lines; but several others, all in the region of short wave-lengths except λ 4843.8, are of comparable strength. Four of the stronger furnace lines of short wave-length, λλ 2879.4, 2896.4, 2944.4, 2947.0, were observed as absorption lines by E. O. Hulburt[1] in the underwater spark. A preliminary report by O. Laporte[2] on a term analysis gives a group of lines arising from combinations of s and D with a higher P-term. Most of these lines are present in the furnace spectrum.

The wave-lengths in Table I are those of M. Belke[3] on the inter-

[1] *Physical Review*, **24**, 129, 1924. [2] *Naturwissenschaften*, **13**, 627, 1925.

[3] *Zeitschrift für wissenschaftliche Photographie*, **17**, 145, 1918.

national system, while the intensities in the arc and in the furnace were estimated by the writer from the spectrograms of the present investigation.

*Rhenium.*—In his comprehensive paper on the neutral spectrum of rhenium, W. F. Meggers[1] was able to indicate the probable energy-levels involved in the production of most of the stronger lines. In his assignment, the lines from the lower levels are in general of high intensity; but since many strong lines appear to belong to the higher levels, the arc data required supplementing by the furnace spectrum before the lines arising from lower levels could be definitely selected. A further purpose of the furnace investigation was to study in a vacuum source the hyperfine structure of the lines given by the furnace, since the arc spectrograms of Meggers had shown that many rhenium lines are highly complex.

Rhenium metal of high purity in the form of a coarse-grained powder was placed in a graphite combustion boat in the furnace tube. After a run, a black residue was found fused to the material of the boat. This indicated the formation of a carbide which fused at a temperature much below the melting-point of the pure metal, since the more sensitive spectral lines appeared with considerable intensity at temperatures from 2700° to 2900° C.

The furnace spectrum was examined from λ 2500 to λ 6700, the second order of the grating being used for wave-lengths shorter than 5500 and the third order for a part of the ultra-violet. As with tungsten, the carbon bands were a disturbing influence at the high temperatures required, and caused uncertainty as to the occurrence of some of the rhenium lines. The lines whose presence was at least probable are listed in Table II. The wave-lengths and arc intensities are those of Meggers, followed by the furnace intensities and hyperfine structures noted in the present work. The final column contains the combinations of levels assigned by Meggers. The furnace lines are found to be from the three lowest levels, as would be expected if Meggers' selection is correct. According to Meggers, several lines of shorter wave-length arise from the ground level, but the arc intensities of these lines are not high, and the furnace spectrum ends at λ 2887. No furnace lines appeared in the red region, and the pre-

[1] *Bureau of Standards Journal of Research*, **6**, 1027, 1931.

vailing high levels found by Meggers for infra-red lines of the arc did not promise results from an extension of the furnace spectrograms beyond the red.

Hyperfine structure is of very frequent occurrence among lines in the arc spectrum of rhenium. Of the lines in Table II, five of those from the ground level are fine examples of "flag" patterns, having from four to six components each, with stronger and wider-spaced

TABLE II

RHENIUM LINES IN FURNACE SPECTRUM

| λ (MEGGERS) | INTENSITY | | NUMBER COMPONENTS | COMBINATION |
|---|---|---|---|---|
| | Arc (Meggers) | Furnace | | |
| 2887.67 | 60 | 1 | 2 | 3–88 |
| 2992.36 | 50 | 15 | 2 | 1–26 |
| 2999.58 | 80 | 3 | 2? | 3–81 |
| 3067.39 | 50 | 10 | 1 | 1–25 |
| 3399.29 | 60 | 2 | 4? | 3–60 |
| 3424.61 | 200 | 3 | 6? | 3–58 |
| 3451.88 | 600 | 40 | 4 | 1–23 |
| 3460.47 | 1000 | 200 | 6 | 1–22 |
| 3464.72 | 800 | 150 | 5 | 1–21 |
| 3549.89 | 5 | ? | 1 | 3–53 |
| 4136.45 | 100 | ? | 4? | 3–36 |
| 4221.08 | 30 | 3 | 2? | 2–34 |
| 4580.67 | 30 | ? | 2 | 2–26 |
| 4758.86 | 15 | 2 | 2 | 2–25 |
| 4889.15 | 2000 | 200 | 6 | 1–18 |
| 5275.54 | 1000 | 100 | 5 | 1–17 |
| 5752.92 | 100 | ? | 4? | 2–23 |
| 5776.81 | 200 | ? | 6 | 2–22 |
| 5834.31 | 500 | ? | 2? | 3–22 |

components toward shorter waves. The components of three of these were resolved on furnace and arc spectrograms, and their wavelengths, measured on third-order plates from iron standards, are as follows:

| | | |
|---|---|---|
| 3451.815 | 3460.359 | 3464.636 |
| .881 | .430 | .700 |
| .929 | .485 | .752 |
| .957 | .531 | .794 |
| | .569 (blend of 5th and 6th) | .824 |

A sixth line from the lowest level, λ 3067.4, appears sharp in furnace and arc. The patterns of the remaining lines are close, having prob-

ably two to six components. In λ 3399.3 and λ 3424.6, the wider-spaced components are toward the red.

The furnace intensities are questioned for six lines. Of these, λλ 3549.9, 4136.4, and 4580.7 are masked by lines of the cyanogen or carbon bands, and if present are very faint. The presence of the strong yellow lines λλ 5752.9, 5776.8, and 5834.3 is also doubtful, as they do not stand out from the rather strong continuous spectrum in this region.

CARNEGIE INSTITUTION OF WASHINGTON
MOUNT WILSON OBSERVATORY
December 1931

# EVIDENCE FOR SPACE REDDENING FROM BRIGHT B STARS

By EMMA T. R. WILLIAMS

ABSTRACT

A comparison of the mean colors of Struve's giants, intermediates, and dwarfs shows that the giants of any class are much reddened and the intermediates are somewhat reddened. The discussion shows that *this is space reddening*, and that the *effect of absolute magnitude is negligible.* Struve's classification is also confirmed by secular parallaxes.

Since the issue between the space-reddening hypothesis and the absolute-magnitude-effect hypothesis in the interpretation of color excess in early type stars[1] has not yet been definitely settled, it is worth while to examine the values of color excess of the B stars recently classified by O. Struve.[2] It will be shown that these data definitely indicate space reddening.

Struve classified the B stars into giants, intermediates, and dwarfs on the basis of four spectral criteria, each of which has a plausible physical basis. For a comparison of the colors of Struve's classes there are available two lists of reliable photo-electric color indices each of which includes a good number of Struve's stars. The list by K. F. Bottlinger[3] includes thirty-three of Struve's stars. C. T. Elvey's[4] list includes forty-nine of Struve's stars. Of these, twenty-four stars were common to all three lists, so that we have colors for fifty-eight stars. The Bottlinger color equivalents, $J$, were reduced to the Elvey system of color equivalents, $C$, by means of Figure 2 of Elvey's paper, i.e.:

$$C = 3.2J + 1.47 .$$

When a star appeared on both Bottlinger's and Elvey's lists, the mean of the two values of $C$ was assigned a weight of 1.4.

Table I shows the mean values of $C$ with probable errors for each of Struve's subclasses. It will be noted that the giants are much red-

[1] Cf., for instance, Öpik, *Harvard Circulars*, No. 359, 1931.

[2] *Astrophysical Journal*, **74**, 225, 1931.

[3] *Veröffentlichungen, Berlin-Babelsberg*, **3**, No. 4, 1923.

[4] *Astrophysical Journal*, **74**, 298, 1931.

der and the intermediates somewhat redder than the dwarfs, the apparent magnitudes being about the same, namely, 3.8, for the three classes. It is also evident that the dispersion in $C$ among the giants is much greater than among the dwarfs, as is evidenced by their probable errors, the probable error of unit weight of the determinations of $C$ for giants averaging .105, for intermediates .091, and for dwarfs .048. Elvey found, from a comparison of his color equivalents with Bottlinger's for the same stars, that the observational probable error is .037. It follows that the actual dispersion in color among the dwarfs of a given subclass is small.

Table I confirms the reality of Struve's divisions: giants, intermediates, and dwarfs. This is further confirmed by the secular

TABLE I

MEAN VALUES OF COLOR EQUIVALENTS

| Class | O | Bo | B1 | B2 | B3 | B4, 5, 6 | B8 | B9 |
|---|---|---|---|---|---|---|---|---|
| Giants... | $-.76\pm7$ | $-.58$ | $-.62\pm7$ | $-.42\pm1$ | $-.16$ | $-.50\pm6$ | $-.68$ | $-.33\pm11$ |
| Intermediates. | .82 | $.78\pm7$ | $.75\pm3$ | ..... | $.73\pm3$ | .64 | ..... | ..... |
| Dwarfs.. | $-.84\pm2$ | $-.93\pm3$ | $-.78\pm7$ | $-.83\pm2$ | $-.70\pm2$ | $-.68\pm1$ | $-.58\pm1$ | ..... |

parallaxes, which were derived as follows. The Boss proper motions were corrected in declination by the Boss and Jenkins corrections[1] and for precession and galactic rotation with the help of Tables 9, 10, 11, and 12 of *Groningen Publication* No. 45, which are based approximately on Oort's determinations of the constants. The $v$ component was reduced to the corresponding $v$ component of a fifth-magnitude star by means of the relation

$$\text{Reduced } v \text{ component} = v \times 10^{.2m-1}.$$

The resulting secular parallaxes of fifth-magnitude stars, together with their probable errors, are shown in Table II. The number of stars in each group ranged from fourteen to twenty. In the other classes there was an insufficient number to justify a determination of secular parallax. The probable errors shown are satisfactorily small and attest the uniformity and care of Struve's classification. Table

[1] *Astronomical Journal*, **37**, 173, 1927.

II also shows the absolute magnitudes, computed on the assumption that $V_0 = 19$ km/sec. There is evidence that this is too small a value of $V_0$ for B stars,[1] so that the absolute magnitudes may be systematically too faint.

Returning to Table I, it was immediately noted on examining the individual values of the color indices that the reddening depended on both $(m-M)$ and galactic latitude. To determine how much of the reddening is due to absolute-magnitude effect and how much

TABLE II

SECULAR PARALLAXES AND ABSOLUTE MAGNITUDES

| Class | Bo, 1, 2 | B3 | B4, 5, 6 |
|---|---|---|---|
| | Secular Parallax of Fifth-Magnitude Stars | | |
| Intermediates | $-''.001 \pm ''.002$ | $+''.010 \pm ''.002$ | ..... |
| Dwarfs | $+''.011 \pm ''.002$ | $+''.019 \pm ''.002$ | $+''.032 \pm ''.009$ |
| | Derived Absolute Magnitudes, Assuming $V_0 = 19$ Km/Sec. | | |
| Intermediates | ..... | $-2.9 \pm 0.5$ | ..... |
| Dwarfs | $-2.9 \pm 0.4$ | $-1.6 \pm 0.3$ | $-0.5 \pm 0.2$ |

is due to space reddening, equations of form (1) were set up for the thirty-two stars within 15° of the galactic equator.

$$C = a(9-s)^2 + b(9-s) + c + d.r + e(M-M_d), \qquad (1)$$

where $a$, $b$, $c$, $d$, and $e$ are constants to be determined; $C$ is the observed color; $s$ is the subclass, 0 for Bo, 1 for B1, etc.; $r$ is the distance of the star in parsecs; $(M-M_d)$ is the absolute magnitude of the star less the absolute magnitude of a dwarf star of the same subclass; this is assumed to be 3.5 for giants, 1.5 for intermediates, and 0 for dwarfs. In order to evaluate $r$ and $(M-M_d)$, it was necessary to adopt values of the absolute magnitudes of the various classes. These values, of necessity rather arbitrary, are given in Table III. In determining these, the recent work of Strömberg[2] on

[1] For instance, G. Strömberg, *Astrophysical Journal*, **74**, 342, 1931.

[2] *Ibid.*

absolute magnitudes of A and B stars was used as a guide in addition to Table II. A least-squares solution was made which gave

$$d = .00007 \pm .00004 \text{ and } e = .050 \pm .014 ,$$

but the residuals showed such a marked dependence on galactic latitude, even in this narrow zone (see Table IV), that the solution was regarded as untrustworthy.

TABLE III

ADOPTED VALUES OF ABSOLUTE MAGNITUDES

| Class | O | Bo | B1 | B2 | B3 | B4, 5, 6 | B8 | B9 |
|---|---|---|---|---|---|---|---|---|
| Giants | −7.5 | −7.0 | −6.5 | −5.9 | −5.3 | −4.5 | −4.0 | −3.5 |
| Intermediates | 5.5 | 5.0 | 4.5 | 3.9 | 3.3 | 2.5 | 2.0 | ..... |
| Dwarfs | −4.0 | −3.5 | −3.0 | −2.4 | −1.8 | −1.0 | −0.5 | ..... |

In order to introduce galactic latitude, $\beta$, into the equations, it was necessary to make some assumption as to the density distribution of the reddening material with respect to the galactic plane.

TABLE IV

| Galactic Latitude | Average Residuals in First Solution |
|---|---|
| $-4°$ to $+4°$ | $-0.05 \pm 0.02$ |
| $-9°$ to $-5°$ and $+5°$ to $+9°$ | $+0.03 \pm 0.03$ |
| $-15°$ to $-10°$ and $+10°$ to $+15°$ | $+0.06 \pm 0.01$ |

The density distribution chosen—which, incidentally, is that for an isothermal atmosphere—was selected because it would reproduce approximately the dependence on latitude indicated by the residuals. Thus we have assumed

$$\text{Density} \propto e^{-z/k} ,$$

where $z$ is the distance in parsecs north or south of the galactic plane. To determine $k$, P. van de Kamp's determination of the thickness of the absorbing layer[1] was used. Van de Kamp assumed a constant density from $z = -z_0$ to $z = +z_0$ and zero density outside these limits. He found $z_0 = 105$ parsecs. Since the total optical thickness of the

[1] *Astronomical Journal*, **41**, 84, 1931.

layer must be a constant, whatever the law of density distribution, we have

$$\frac{\text{Optical thickness}}{\text{Constant}} = \int_0^\infty e^{-z/k} dz = \int_0^{105} dz = 105 ,$$

whence

$$k = 105 .$$

Now the reddening of any star at a distance of $r$ parsecs and at galactic latitude $\beta$ will be proportional to

$$\int_0^r e^{-\frac{r \sin \beta}{105}} dr = \frac{105}{\sin \beta} \left( 1 - e^{-\frac{r \sin \beta}{105}} \right) = F(r, \beta) ,$$

since $z = r \sin \beta$. In Table V we have tabulated values of $F(r, \beta)$ for various values of $r$ and $\beta$.

TABLE V

EFFECTIVE REDDENING PATH, $F(r, \beta)$

| $r$ in Parsecs | 50 | 100 | 200 | 300 | 400 | 500 | 650 | 800 | 1000 | 1200 | 1500 | ∞ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\beta$ 0°..... | 50 | 100 | 200 | 300 | 400 | 500 | 650 | 800 | 1000 | 1200 | 1500 | ∞ |
| 3..... | 50 | 98 | 191 | 279 | 360 | 445 | 555 | 660 | 785 | 905 | 1055 | 2010 |
| 10..... | 48 | 93 | 171 | 236 | 293 | 340 | 400 | 445 | 490 | 520 | 555 | 605 |
| 20..... | 46 | 86 | 147 | 185 | 256 | 247 | 270 | 284 | 291 | 300 | 305 | 305 |
| 50..... | 41 | 69 | 104 | 120 | 128 | 132 | 135 | 136 | 137 | 137 | 137 | 137 |
| 90..... | 40 | 65 | 89 | 100 | 103 | 104 | 105 | 105 | 105 | 105 | 105 | 105 |

In Table V, $r$ is the true distance of the star. The value of $r$ derived from the usual formula

$$r = 10^{.2(m-M)+1}$$

must be corrected for the absorption of visual light. R. J. Trumpler[1] found an absorption coefficient of $0^m.35$ per 1000 parsecs close to the galactic equator. If we assume that the same matter is responsible for this absorption as for the differential absorption, then the correction to $r$ is a function of latitude. Table VI gives the values of $(m-M)$ corresponding to various distances and latitudes assuming

[1] *Lick Observatory Bulletin*, 14, 154, 1930.

Trumpler's absorption coefficient and the same density distribution assumed in Table V.

New equations were now set up in the form of equation (2),

$$C=b'(9-s)+c'+d'F(r,\beta)+e'(M-M_d)\,, \qquad (2)$$

where $b'$, $c'$, $d'$, and $e'$ are constants to be determined and the other quantities have the same significance as in the form of equation (1). In order to shorten the work, all equations were weighted equally and the five O stars were omitted in order that the second-degree

TABLE VI

VALUES OF $(m_v-M_v)$, ASSUMING TRUMPLER'S ABSORPTION COEFFICIENT

| $r$ in Parsecs | | 50 | 100 | 200 | 300 | 400 | 500 | 650 | 800 | 1000 | 1200 | 1500 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\beta$ | 0° | 3.5 | 5.0 | 6.6 | 7.5 | 8.2 | 8.7 | 9.3 | 9.8 | 10.3 | 10.8 | 11.4 |
| | 3 | 3.5 | 5.0 | 6.6 | 7.5 | 8.1 | 8.7 | 9.3 | 9.7 | 10.2 | 10.7 | 11.2 |
| | 10 | 3.5 | 5.0 | 6.6 | 7.5 | 8.1 | 8.6 | 9.2 | 9.7 | 10.2 | 10.6 | 11.1 |
| | 20 | 3.5 | 5.0 | 6.6 | 7.5 | 8.1 | 8.6 | 9.2 | 9.6 | 10.1 | 10.5 | 11.0 |
| | 50 | 3.5 | 5.0 | 6.5 | 7.4 | 8.1 | 8.5 | 9.1 | 9.6 | 10.0 | 10.4 | 10.9 |
| | 90 | 3.5 | 5.0 | 6.5 | 7.4 | 8.0 | 8.5 | 9.1 | 9.6 | 10.0 | 10.4 | 10.9 |

term $a'\,(9-s)^2$ might be omitted. There were fifty-three observation equations which yielded the following:

$$C=-.040(9-s)-.59+.00058F(r,\beta)+.009(M-M_d)\,. \qquad (3)$$
$$\pm.004 \qquad \pm.02 \pm.00006 \qquad \pm.008$$

The probable error of unit weight in this solution was .063 as compared with a probable error of unit weight of .091 in the solution which was discarded. In order to reduce these values to those of the International System of color indices, it is necessary to correct for scale and for zero point, and this cannot be accurately done since the spectral regions used by Elvey and Bottlinger are not those of the effective wave-lengths of photovisual and photographic magnitudes. However, as a very rough approximation equation (3) has been translated into the International System below:

$$\text{Observed color}=-{}^{m}.026(9-s)-{}^{m}.03+{}^{m}.00038F(r,\beta)+{}^{m}.006(M-M_d)\,. \qquad (4)$$
$$\pm.002 \qquad \pm.02 \pm.00004 \qquad \pm.005$$

It is seen from the last term that the *absolute magnitude effect is only* $^{m}.02 \pm .02$ *for a giant, i.e., entirely negligible, whereas the differential absorption or space reddening at 1000 parsecs in the galactic plane is unquestionably real,* $0^{m}.38 \pm .04$. This value falls fairly close to van de Kamp's determination of the differential absorption coefficient of $0^{m}.33 \pm .02$ per 1000 parsecs.[1]

The coefficient of the first term and its small probable error indicate that the color temperatures of B stars, unaffected by space reddening, present precisely the trend predicted by the ionization theory.

The residuals of the last solution would place the sun slightly south of the center of the absorbing layer, but as only fourteen of the fifty-three stars were north of the galactic plane the result is not very trustworthy. The residuals also indicate that the absolute magnitudes assumed for the intermediates were too bright by perhaps half a magnitude relative to the absolute magnitudes assumed for the giants and dwarfs.

The probable error of unit weight derived from the residuals is $0^{m}.04$ on the International System for the dwarfs; it is $0^{m}.05$ for the intermediates and $0^{m}.06$ for the giants. The observational error determined by Elvey as mentioned above amounts to $0^{m}.024$ on the International System.

Another solution was made using only the thirty-six Bo, B1, B2, and B3 stars, since these are the stars usually suspected of showing a large absolute-magnitude effect. The resulting coefficients were very little altered from those in equation (4), however.

Also a solution was made neglecting the effect of Trumpler's absorption coefficient. This gave a slightly smaller value of $d'$, but $e'$ remained about the same.

In conclusion I wish to thank Professor van de Kamp for his helpful criticism and suggestions.

LEANDER MCCORMICK OBSERVATORY
UNIVERSITY OF VIRGINIA
February 15, 1932

[1] *Op. cit.*, **40**, 145, 1930.

## NOTE ADDED IN PROOF

Recent work by B. J. Bok[1] indicates that Trumpler's coefficient may be too large. If Bok's value of the absorption coefficient for photographic light, $0^m.4$ per 1000 parsecs, is correct, it follows from the present investigation that the absorption coefficient for visual light is relatively small. This is borne out by the material used by van de Kamp in his investigation of the thickness of the absorbing layer referred to above. Six of the ten determinations of $z_0$ made by van de Kamp are independent of Trumpler's coefficient. The weighted mean of these six gives $z_0 = 155 \pm 20$ parsecs. Three of the other four determinations involve Trumpler's coefficient for visual light and the weighted mean of these gives $z_0 = 50 \pm 50$ parsecs. This difference in the value of $z_0$ would disappear if the absorption coefficient for visual light were $0^m.1$ per 1000 parsecs instead of $0^m.3$ as found by Trumpler. A new solution has been made with revised values of $F(r, \beta)$ derived by putting $k$ equal to 155 and neglecting the effect of an absorption coefficient in visual light on the observed visual magnitudes. This changes the coefficient of the third term of (4) from $^m.00038$ to $^m.00029$, while the other coefficients and the probable errors remain substantially unchanged.

On the other hand, the investigation of Bottlinger and Schneller[2] on the distribution of Cepheids pointed to a much greater value of the photographic absorption coefficient, $2^m.0$ per 1000 parsecs, when they assumed an absorbing layer of uniform density. As they pointed out, if they had assumed the layer densest along the central plane of the galaxy their results would be very considerably modified. From a very rough computation it appears that their data require either a much steeper density gradient than that assumed in Table V of this paper (which would correspond to a much smaller value of $z_0$ than 105), or a photographic absorption coefficient much greater than $0^m.4$.

[1] *Harvard Circulars*, 371, 1932.

[2] *Zeitschrift für Astrophysik*, I, 339, 1930.

# SPECTRAL ENERGY-DISTRIBUTION OF THE HIGH-CURRENT VACUUM TUBE[1]

By J. A. ANDERSON

ABSTRACT

1. *Continuous spectrum from vacuum tubes.*—When the current density is greater than 10,000 amp./cm², a continuous spectrum appears which is *independent* of the *material* of the *electrode* and the *residual gas*. With increasing current density this spectrum at first increases very rapidly in intensity, then progressively slower, thus suggesting an approach to saturation. The intensity of the continuous spectrum at a given current density also depends on the thickness of the layer of luminous gas observed, very much as if the gas had a definite absorption coefficient.

2. The energy-curve was determined for the region λλ 3400–8000. From λ 4000 to λ 8000 it has very nearly the form of a black-body curve for 10,000° K.

3. The *absolute intensity* was measured and found to be approximately *14 times as great* as that of a black body at 10,000° K.

## 1. INTRODUCTION

In 1921[2] the discharge of a 1-microfarad condenser was passed through a vacuum tube of fairly large bore in an attempt to increase the relative intensity of the multiply ionized lines of oxygen and nitrogen. It was observed that as the current through the tube was increased, these lines at first increased rapidly in intensity, reaching a maximum when the condenser was charged to about 6000 volts. At higher voltages (larger currents in the tube), a continuous background was noted in the spectrum, accompanied by a strong development of lines due to *Si* II and *Si* III, and at the highest voltage available (20,000 volts), the continuous spectrum was strong enough to mask many of the bright emission lines.

The vacuum tube had a diameter of 2 cm, a length of 30 cm, and was observed end on. The frequency of oscillations in the discharge was 87,000.

During the following years similar experiments were tried with different condensers, with tubes of various shapes and sizes, and with residual gases other than air, but the results were always the same: at high current densities a strong continuous spectrum always appeared and effectively prevented the further development of lines

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 449.

[2] *Yearbook of the Carnegie Institution of Washington*, No. 20, p. 291, 1921.

belonging to the higher states of ionization. This result led to a more systematic study[1] of the conditions under which the continuous spectrum appears. The main conclusions from this investigation may be stated as follows:

1. If the current density is less than 10,000 amp./cm², the continuous spectrum is rather weak provided the depth of the luminous column is not greater than 10 cm and the gas pressure not much above 1 cm of mercury. Columns longer than 10 cm and gas pressures higher than 1 cm of mercury have not been studied.

2. With a current density of 20,000 amp./cm² the continuous spectrum is strong if the column has a length of 10 cm, and of moderate intensity in a column 1 cm long (a 1-cm tube viewed side on). Varying the pressure from a few tenths of a millimeter to about 1 cm of mercury has little if any effect.

3. With current densities of the order of 30,000 amp./cm² the continuous spectrum is very brilliant, and in a tube 10 cm long and 1 cm in diameter the intensity is practically the same side on and end on. Since the maximum current obtainable from the condenser available (2 microfarads, 35,000 volts, and 60,000 cycles) was roughly 25,000 amp., current densities in excess of 30,000 required the use of tubes having a diameter less than 1 cm. Pyrex tubes down to 5 mm in diameter were tried, but they lasted only a short time. The first discharge generally produced innumerable small cracks on the inside surface of the tube, and these, deepening with each subsequent discharge, soon caused the tube to fail.

Tubes of fused quartz were, however, found to be quite satisfactory, for in these the inside surface remained smooth and highly polished indefinitely. Internal diameters of the constricted portion as small as 1 mm were used.

4. With high currents the intensity of the continuous spectrum increases at a diminishing rate with increase in current, thus indicating an approach to saturation. The current density actually required for saturation depends on the depth of the layer of luminous gas. For a thickness of 1 cm it appears to be of the order of 30,000 amp./cm², while at least 100,000 amp./cm² is required if the layer is 1 mm thick.

[1] *Ibid.*, No. 27, pp. 145–146, 1927–1928; No. 28, pp. 138–139, 1928–1929.

5. If the tube has a capillary portion only 1 or 2 mm in internal diameter, and if very strong discharges are used, it is found that the bore of the constricted portion is gradually enlarged, the pressure of the gas in the tube increases, and the parts of the tube away from the capillary become coated with a dark deposit. Examination shows that the added gas is oxygen and that the black deposit is silicon. This suggests that silicon dioxide is evaporated from the inner surface of the capillary, and dissociated into oxygen and silicon by the strong discharge. To test this hypothesis quantitatively a fresh tube was operated for some weeks in such a way as to permit a reasonably accurate measurement of the total volume of oxygen evolved. The result was 135 cc at normal temperature and pressure, and measurements of the capillary before and after the experiment showed that the mass of fused quartz evaporated was 370 mg. The corresponding mass of oxygen is 197 mg, or 152 cc at normal temperature and pressure. The discrepancy is only slightly greater than the probable error in measuring the volume of oxygen.

6. Spectrograms made with a concave grating of 1 m focus and a fused-quartz tube side on, excited so as to give a continuous spectrum, show the following:

*a*) *Narrow absorption lines.*—The group of *Si* I lines between λ 2507 and λ 2528, the *Si* I line at λ 2613 (weak), and the *Si* I line at λ 2881 (strong, widened to the red). A few *Si* I lines between λ 2500 and λ 2000 may be seen, but the one at λ 3905 appears to be absent. No other absorption lines have been observed.

*b*) *Emission lines.*—*Si* II: λλ 3856, 3862, 4128, 4131, 5042, and 5056, all wide and hazy; *Si* III: λλ 2541 (rather narrow), 2559 (weak), 3086 and 3093 (moderate), perhaps traces of others, very difficult to see on account of the continuous spectrum.

No lines of other elements have been found.

It has long been known that the capillary portion of a Plücker tube gives a continuous background in its spectrum when a strong condensed discharge is employed, which is in agreement with the results just stated, for an easy calculation shows that current densities of the order mentioned above are not unreasonable in a capillary tube having a diameter of about a millimeter. Let the condenser be a Leyden jar having a capacity of 0.0006 microfarad and let it be

assumed that the inductance in the circuit is of the order of 0.001 millihenry. The frequency of such a circuit would be approximately $6 \times 10^6$, and with a potential of 10,000 volts the maximum discharge current would be approximately 200 amp., thus giving a current density in the capillary of somewhat more than 25,000 amp./cm$^2$.

The existence of what in paragraphs 3 and 4 has been called "saturation" can be explained if it is assumed that the gas becomes more and more opaque as the current density increases. Consider the tube 10 cm long and 1 cm in diameter carrying a maximum current density of 30,000 amp./cm$^2$. Observation shows that the brightness end on and side on is nearly the same, while the depth of the layer of luminous gas when viewed end on is ten times that in the side-on view. If there were no absorption, the brightness end on should be roughly ten times as great as side on; but if the absorption in 1 cm is nearly complete, the brightness end on would only slightly exceed that side on, as is the case. Therefore it appears that absorption increases with the emissivity; hence, qualitatively, Kirchhoff's law seems to apply, although in this type of source there is, of course, no a priori reason to expect this to be the case.

## 2. THE BRIGHT-LINE EMISSION

The object of the present experiments was to determine the spectral energy-distribution of the high-current vacuum tube from λ 8000 to as far into the ultra-violet as practicable. The numerous spectrograms made previously show that the continuous spectrum extends throughout the whole region that can be photographed with a concave grating in air and has a maximum of photographic intensity in the vicinity of λ 4000. As already mentioned, the spectrograms also show a number of bright lines (*Si* II and *Si* III), and a preliminary study was made to determine whether or not these were emitted simultaneously with the continuous spectrum. To settle this point, it was necessary to move a narrow spectrum of the source rapidly over the photographic film perpendicularly to the length of the spectrum. The arrangement of the apparatus is shown in Figure 1. Light from the tube *S* passes through a slit *A* in the plane of the paper, is dispersed in a direction normal to the paper by the Amici prism *B*, and brought to a focus on the slit *D* of the rotat-

ing-mirror camera by the lens *C*. The slit *D* is parallel to the dispersion, that is, at right angles to the plane of the diagram. The narrow linear spectrum passing through *D* is focused by the lens *E* on the curved film *G* after reflection from one of the faces of the octagonal rotating mirror *F*. The image of the spectrum on *G* had a width of less than 0.1 mm and moved over *G* at a speed of approximately 400 m/sec.

Two spectrograms made in this way are reproduced in Plate XVII*a*, *b*. One of these (*a*) was taken with low dispersion (one 60° prism instead of the Amici prism) and shows the spectrum from about λ 5500 to λ 3800. The photographic minimum near λ 5000 causes the red end of the spectrum to resemble an emission line. It will be noticed that light strong enough to affect the plate is shown in

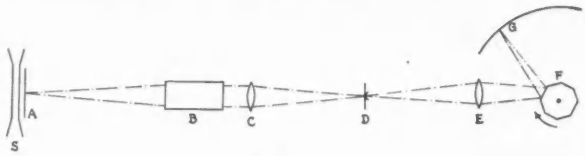
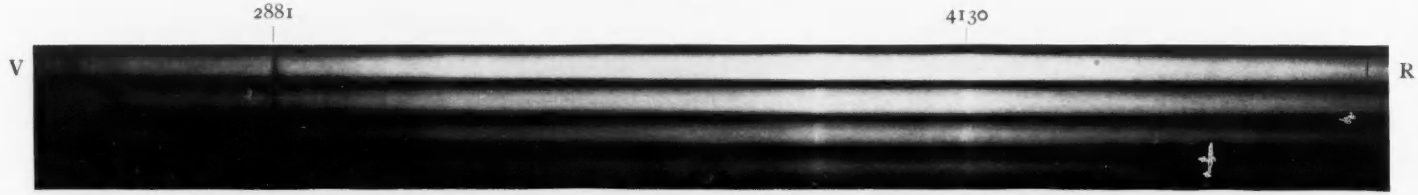



FIG. 1

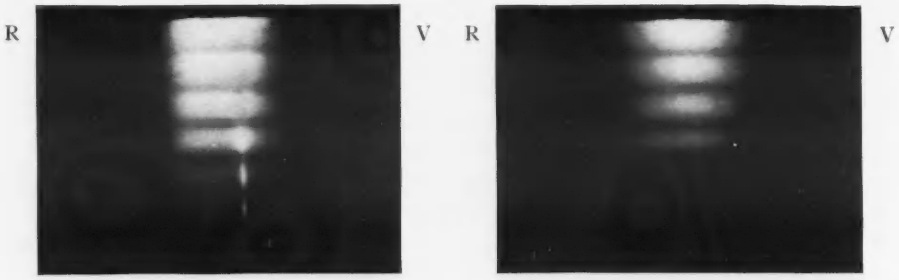
seven half-oscillations of the discharge circuit. The frequency was 60,000 cycles; hence the duration of each half-oscillation was 1/120,000 sec. Emission lines begin to show in the fourth half-oscillation, and they persist without much change to the end. The lines are certainly absent from the first two half-cycle bands.

The other spectrogram (Plate XVII*b*) was made with the higher dispersion of the Amici prism and covers the region λ 5100 to about λ 4300. Again seven bands show on the original plate, the seventh being exceedingly faint; only five, however, are visible in the reproduction. This region is nearly free from emission lines, although on the original plate the *Si* III group at λλ 4574–4552 and *Si* II λ 5056 and λ 5042 show very faintly from the fourth band on. An interesting feature may be noticed at the very beginning of the first band—where for something less than $10^{-6}$ sec. a number of bright lines appear, all due to air. This is no doubt the high-current vacuum-tube equivalent of the so-called pilot spark in an ordinary condensed discharge, which shows air lines chiefly, no matter what metal is used in the electrodes.

## PLATE XVII




*c*




*a* *b*

*a*) Rotating-mirror spectrogram λ 5500 to λ 3800. The strong emission line is a blend of Si II λλ 4131 and 4128.

*b*) Rotating-mirror spectrogram, higher dispersion, λ 5100 to λ 4300.

*c*) Grating spectrogram, integrated light. Reading from bottom to top, exposures were to 1, 2, 4, and 8 discharges through tube.

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A third spectrogram (Plate XVII*c*) was made with the 1-m focus concave grating and is simply an integration of the light emitted during all the oscillations in the circuit. The absorption lines λ 2881 and the group λλ 2507–2528 are quite black, showing that the absorption is present throughout the whole time of the discharge.

The appearance of emission lines in the fourth to seventh half-oscillations is just what one would expect in view of the experimental results described in the first section of this paper. The tube used in making the spectrograms in Plate XVII had an internal diameter of approximately 4 mm, and the maximum current during the first half-cycle was about 20,000 amp. (damping neglected), which corresponds to a current density of something like 150,000 amp./cm². In the succeeding half-oscillations the maximum current fell off ex-

FIG. 2

ponentially at such a rate as to make it very small in the seventh half-oscillation and too small in the eighth to excite appreciable luminosity. It is reasonable to suppose, therefore, that in the fourth half-oscillation the current density had fallen to or below the value required for saturation with a 4-mm layer of luminous gas, and that from then on a discontinuous spectrum would be radiated. Why the only bright lines should be those of *Si* II and *Si* III with air as the residual gas is probably accounted for by the results given in paragraph 5.

### 3. EXPERIMENTAL ARRANGEMENT

The diagram in Figure 2 shows the arrangement used in measuring the spectral energy-distribution of the tube. Light from the tube *A* was focused on the slit of the quartz monochromator *C* by the lens *B*, which, for part of the work, was a small quartz fluorite achromat; for the rest, a pair of quartz lenses. The light emerging from the monochromator was focused on the vacuum thermocouple *E* by a small quartz lens *D*. The thermocouple current was measured by a

Leeds and Northrup high-sensitivity galvanometer. A broad-filament tungsten lamp operated at a known temperature could be substituted for $A$ without any change in the other apparatus.

To determine the shape of the spectral energy-curve it is necessary only to observe the deflections for a number of wave-lengths and to reduce these to the same spectral range by applying the proper correction for the dispersion of the monochromator.

A determination of the real brightness of the source at a given wave-length is somewhat more complicated; the following considerations indicate how it may be accomplished: The deflection $a$ given by a broad-filament tungsten lamp at a certain wave-length is read. The widths of both entrance and exit slits are noted, and the projection lens is so placed that the image of the filament completely covers the entrance slit. Then the vacuum tube is substituted for the lamp, all other parts of the apparatus remaining undisturbed except the widths of the two slits, which are adjusted to give a deflection $b$ of the same order as that given by the lamp. In the case of deflection $a$ the exposure is long enough for both thermocouple and galvanometer to reach a steady state, while for $b$ the duration of the exposure is very short—so short, in fact, that neither the temperature of the thermojunction nor the position of the galvanometer coil is changed appreciably while it lasts. The only thing that happens is a sudden warming-up of the layer of soot covering the thermojunction. The heat energy absorbed is immediately transferred in part to the junction by conduction and in part to the surrounding objects by radiation; in a short time $T$, comparable with the "lag" of the thermocouple, the temperature of the junction reaches a maximum from which it falls to normal in another interval of about the same length. During the interval $2T$ a variable current passes through the galvanometer and produces the deflection observed.

When the thermocouple is exposed to the radiation from a steady source, such as a lamp, the junction reaches an equilibrium temperature in a time $T$ and remains there as long as the exposure lasts. If the exposure is longer than the interval $T'$, the period or lag of the galvanometer, the deflection of the galvanometer coil also becomes constant. If the exposure is shorter than $T'$, the deflection will, of course, be smaller; and very much smaller if the exposure time is only

a small fraction of $T'$. In the latter case the galvanometer may be said to be used as a "ballistic instrument," that is, its deflection may be taken as a measure of the quantity of electricity passing through it, which in the case considered is simply the current from the thermocouple multiplied by the time of exposure. The current from the thermocouple is proportional to the temperature difference of the two junctions, which in turn is proportional to the energy falling on the junction exposed to radiation. It follows that the deflections will be proportional to the product of the energy by the time, when the time is very short in comparison with the period of the galvanometer, at least in the case where the thermocouple responds so quickly that it may always be regarded as in equilibrium with the incident radiation. But even if the thermocouple has an appreciable lag, the same will be true, provided losses by radiation and conduction both vary linearly with the difference of temperature of the two junctions. This is always true for conduction, and in the case of moderate differences of temperature it is also true for radiation. For large differences of temperature, losses by radiation increase somewhat faster than a linear rate, with the result that the deflections produced are too small.

Hence, if the exposure time $\Delta t$ is short in comparison with the period of the galvanometer, the deflection is

$$D = KE_\lambda d\lambda \Delta t \,, \tag{1}$$

where $K$ is a constant of the apparatus and $E_\lambda$ has its usual significance. For exceedingly small values of $\Delta t$ it is probable that $K$ decreases slightly, as explained above.

It is now clear how $E_\lambda$, or rather a lower limit to the value of $E_\lambda$, may be determined for short-lived sources such as the high-current vacuum tube. In addition to the two observations specified above, it is necessary to take a series of exposures of known duration to a constant continuous source, such as the lamp, in order to determine the constant $K$ in equation (1). Since $K = D/E_\lambda d\lambda \Delta t$, it is necessary only to plot the deflections against the exposure times. For sufficiently small values of $\Delta t$ the curve should be a straight line whose slope is $KE_\lambda d\lambda$, and, $E_\lambda d\lambda$ being supposed known, $K$ is determined. The evaluation of $\Delta t$ will not in general present any serious difficulty.

### 4. SHAPE OF THE ENERGY-CURVE

Figure 3, curve *A*, shows the deflections, corrected for the dispersion of the monochromator, plotted as ordinates against wave-lengths as abscissae. The humps at λλ 3800, 4100, and 5000 are conspicuous, and there is a much smaller one near λ 6000. As already explained, these are due to the *Si* II lines, which are bright during the later stages of the discharge. The lines responsible for the various humps are indicated on the axis of abscissae. The observations from which

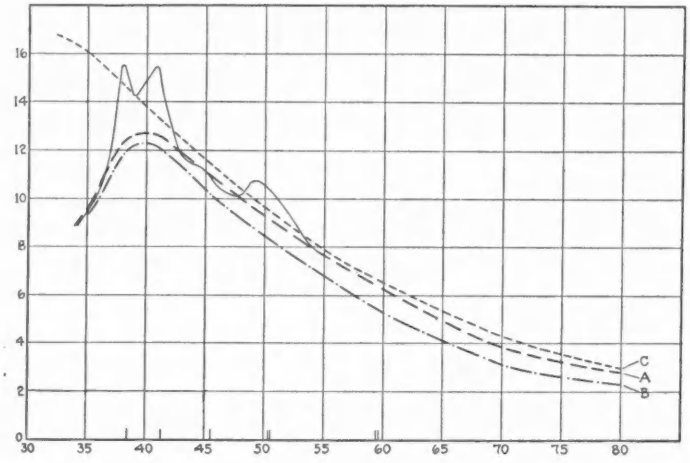


FIG. 3

curve *A* is plotted were made with the condenser charged to approximately 30,000 volts. Another series of observations was made with 14,000 volts on the condenser, and the difference between the two series is plotted in curve *B*. It will be noticed that the humps have disappeared, and also that curve *B* rises a little more rapidly from red to blue than curve *A*. The explanation is very simple. Curve *A* represents an integration of all the seven half-oscillations shown in Plate XVII*a*, for the photograph for this illustration was also taken with 30,000 volts on the condenser. On account of damping, the potential of the condenser diminishes exponentially in such a way that in the eighth half-oscillation it is too small to activate the tube. On the assumption that it falls to 0.7 of its value in each successive half-oscillation, the potential in the third half-period would be 14,700

volts, or almost the same as that used in making the second set of observations just mentioned. The difference between the two sets of observations would then be almost precisely the light emitted in the first two half-oscillations of Plate XVII*a*. These radiations, as already noted, are quite free from emission lines; and curve *B* shows that the light is a trifle bluer than the average of the continuous spectrum for the whole discharge, although the difference is not great.

Curve *C*, Figure 3, represents the distribution of energy for a black body at 10,000° K, multiplied by a factor which makes its ordinate at λ 8000 comparable with that of curve *A*. The agreement is good from λ 8000 to λ 4000, beyond which curve *A* falls off considerably. Curve *B* corresponds more nearly to a black-body curve for a temperature of 10,500° K. A few observations were made between λ 3500 and λ 2500, where, on account of the large dispersion of the monochromator, the deflections are rather small and, consequently, the accuracy very much reduced. The value of $E_\lambda$ diminishes with the wave-length in this region and at λ 2500 appears to be of the order of twice that at λ 8000.

### 5. ABSOLUTE VALUE OF $E_\lambda$

Since the energy-curve in the region λλ 8000–4000 is practically parallel to the black-body curve for 10,000° K, it will be sufficient to determine the real value of $E_\lambda$ for one wave-length only. The wave-length λ 6500 was chosen in order to make direct use of the properties of tungsten given by W. E. Forsythe and A. G. Worthing.[1] Among other things they give the brightness temperature for λ 6650 corresponding to various values of the true temperature, color temperature, etc. The values for λ 6650 will not differ appreciably from those pertaining to λ 6500.

The following observational data are needed for the calculation of $E_\lambda$ for the vacuum tube at λ 6500:

1. The deflection given by a ribbon tungsten lamp at λ 6500, operated at a true temperature of 2635° K with entrance slit 0.05 mm and exit slit 0.10 mm, was 5.47 cm.

2. Various experiments both with lamps and with the vacuum

[1] *Astrophysical Journal*, **61**, 152, 1925.

tube have shown that the deflections are proportional to the widths of both slits.

3. Exposures to a lamp for various lengths of time gave the accompanying results:

| Exposure Time | Deflection |
|---|---|
| 1.0 sec. | 1.00 cm |
| 2.0 | 1.92 |
| 3.0 | 2.69 |
| 4.0 | 3.21 |
| >10 | 4.16 |

For exposures of less than 1 sec. the deflections are proportional to the exposure time, and the 1-sec. deflection may be taken as one-fourth of the steady deflection.

4. The vacuum tube (condenser charged to 28,000 volts) gave a deflection of 6.47 cm with entrance slit 0.2 mm and exit slit 0.4 mm.

Reducing the lamp deflection to the slit widths used with the tube introduces a factor of 16, and to an exposure time of 1 sec. (factor one-fourth) gives the value $4\times 5.47$ cm $= 21.88$ cm. It now remains to reduce the vacuum-tube deflection to the standard time of 1 sec., which involves the effective duration of the discharge, $\Delta t$ in equation (1).

Let $I_0$ be the average intensity during the first half-oscillation and assume that it decreases exponentially in the following pulses, being $I_0 e^{-\alpha}$ in the second, $I_0 e^{-2\alpha}$ in the third, and so on. We require the value of $I_0 e^{-6\alpha}$, the intensity in the seventh half-oscillation, which is very small; but for fear of underestimating it we set it equal to $0.01 I_0$. This gives $\alpha = 0.472$, and the total intensity $= 1.894 I_0$. Consequently, if the intensity remained constant at the value $I_0$, the time required for the emission of the energy $1.894 I_0$ would be 1.894 times the duration of a half-oscillation, or $1.894 \times 1/120{,}000$ sec. $=$ $1/63{,}000$ sec.

Substituting in equation (1) and writing $E_\lambda(L)$ for the lamp and $E_\lambda(T)$ for the vacuum tube, we have

$$\left.\begin{aligned} 21.88 &= K E_\lambda(L), \\ 6.47 &= \frac{1}{63{,}000} K E_\lambda(T), \end{aligned}\right\} \qquad (2)$$

where $d\lambda$ has been omitted since the deflections have been corrected for slit widths, with the result that

$$E_\lambda(T) = 18{,}900\, E_\lambda(L), \tag{3}$$

where $E_\lambda(T)$ is the average intensity during the first half-oscillation. The maximum intensity is somewhat greater than this, and if we could assume that the intensity varies as the square of the current density, it would be just twice the value given. Observations of the deflections as a function of the voltage of the condenser give the accompanying values for λ 7000:

| | | | |
|---|---|---|---|
| Volts | 14,000 | 20,000 | 28,000 |
| Deflection | 0.96 | 3.04 | 4.15 |

These values show that between 14,000 and 20,000 volts the deflections increase a little faster than the square of the voltage, but a little slower between 20,000 and 28,000 volts. Hence, while the maximum intensity is undoubtedly greater than the average value given above, it is probably not quite twice as great. This would also affect slightly the calculation of $\Delta t$ given above, but so slightly that for the present it may be ignored.

Equation (3) states that at λ 6500 the average intensity of the tube during the first half-cycle was 18,900 times the intensity of the tungsten ribbon lamp. This lamp was made and calibrated by the Philips Lamp Works of Eindhoven, Holland. The calibration-curve gives the true temperature and the color temperature for various values of the current in the lamp. The readings utilized above were made at a true temperature of 2635° K, or a color temperature of 2700° K. As a rough check on the calibration, readings were made at intervals of 500 A between λ 6000 and λ 8000 for currents corresponding to 2600° and 2700° K. The color temperature deduced from the observed deflections came out a trifle higher than that given by the calibration-curve.

According to Forsythe and Worthing's work the brightness temperature at λ 6650 for a true temperature of 2635° K is 2384° K, and, as the emissivity of tungsten increases slowly toward shorter wavelengths, the brightness temperature is probably not less than this at

λ 6500; for the present reduction, however, we will take the round value 2380° K as the black-body temperature to be used in computing $E_\lambda(L)$ in equation (3). By Planck's law we find that at λ 6500 the value of $E_\lambda$ for 10,000° K is 1323 times its value for 2380° K. But according to equation (3) the value of $E_\lambda$ for the vacuum tube is 18,900 times this same value, so that *although the energy-curve for the tube between λ 8000 and λ 4000 is very like that of a black body at 10,000° K, the actual values of the ordinates are 14 times as large.* As already stated, this applies to the average intensity of the tube during the first half-oscillation. The maximum intensity is higher than this, although for the reasons given above it is probably not quite twice as great.

The color temperature of this source in the visible spectrum is 10,000° K, while the brightness temperature computed for the regions λ 4500 and λ 7000 comes out 33,000° and 52,000° K, respectively. Even at λ 3500, where the relative intensity is much below the 10,000° K curve, the brightness temperature is 19,000° K. Hence, throughout the region studied, the brightness temperature is from two to more than five times the color temperature.

CARNEGIE INSTITUTION OF WASHINGTON
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# ON THE VARIABLE LINES OF HELIUM AND MAGNESIUM IN THE SPECTRUM OF 13 $\mu$ SAGITTARII

By W. W. MORGAN

ABSTRACT

The absorption lines *He* I 4471 and *Mg* II 4481 have been found to vary in intensity in the spectrum of the long-period spectroscopic binary $\mu$ Sagittarii. The variation is in the period of orbital revolution of the binary system, $\lambda$ 4471 rising to a sharp maximum at the time of periastron, while $\lambda$ 4481 decreases to a minimum at the same time. It is probable that the helium line, $\lambda$ 4026, varies in phase with $\lambda$ 4471, while four other lines, due to the same element, do not show any measurable variation. The silicon and hydrogen lines may be variable, but the material is not complete enough or sufficiently homogeneous to permit certainty. The variability of the absorption lines is probably due, in some manner, to the close approach of the two stars at periastron, as the eccentricity of the system is high and the principal star is a supergiant.

During an examination of Yerkes spectrograms I have recently found several lines in the spectrum of 13 $\mu$ Sagittarii which vary greatly in intensity in the period of variation in velocity. The star was found to be a spectroscopic binary by Frost and Adams.[1] An orbit was computed by N. Ichinohe[2] from measures of a series of spectrograms having a dispersion of one prism which had been ob-

TABLE I

| | |
|---|---|
| $P = 180^d.2$ | $\gamma = -8.23$ km/sec. |
| $K = 66.82 \pm 1.23$ km/sec. | $T =$ J.D. $2417495.64 \pm 0^d.80$ |
| $\omega = 79°.13 \pm 2°.44$ | $a \sin i = 148{,}110{,}000$ km |
| $e = 0.447 \pm 0.013$ | $(m_1 + m_2) \sin^3 i = 4.0 \odot$ |

tained with the Bruce spectrograph of the Yerkes Observatory. The plates were remeasured by O. Kohl[3] and a new orbit was derived by him. The two sets of elements are in good agreement. The orbital elements as found by Kohl are given in Table I. As only one spectrum is visible the ratio of the masses of the two stars cannot be determined.

The spectrum of $\mu$ Sagittarii is given as B8p by the *Henry Draper Catalogue*. The *c*-characteristic is marked, and the spectrum is quite

[1] *Astrophysical Journal*, **19**, 351, 1904.

[2] *Ibid.*, **26**, 157, 1907.

[3] *Astronomische Nachrichten*, **219**, 213, 1923.

similar to that of $\beta$ Orionis. The *H* lines are narrow, and the strongest lines other than those of hydrogen are due to *He* I, *Mg* II, and *Si* II. The H and K lines of *Ca* II are outside the range of Yerkes spectrograms.

An examination of the series of plates used by Ichinohe and Kohl for determining the orbital elements showed that the relative intensity of the lines *He* I 4471 and *Mg* II 4481 varied markedly. An intercomparison of the plates showed that both of the lines were variable, but in a complementary manner, magnesium being faint when the helium line was strongest and the helium line becoming weak when magnesium reached its greatest intensity. The other member of the $2^3P-m^3D$ series of helium in the observable range, which lies at λ 4026, probably varies in phase with λ 4471, but the plates are weak to the violet of λ 4200 and estimates of intensity are uncertain. The lines λ 4121 and λ 4713 of the $2^3P-m^3S$ series and the singlets at λ 4144 and λ 4387 are constant in intensity within the errors of observation.

When the estimated intensities of the variable lines were plotted against the spectroscopic period, it was evident that both intensities and radial velocity varied in the same period. λ 4471 remained faint for most of the period with a sudden augmentation in strength near the time of periastron, followed by an equally rapid diminution. There is probably a slight lag in the time of the maximum of λ 4471 as compared with the time of periastron passage, but the connection between the two phenomena seems certain. Table II gives the estimated intensities of a selected group of lines. The variation in intensity of λ 4471 and λ 4481 is shown in Figure 1, together with Ichinohe's velocity-curve. The time of periastron passage is shown on the diagram. The points in parentheses in the plots of λ 4471 and λ 4481 are estimates made on an overexposed plate. If the plate had been of the proper intensity the estimates would probably have fallen near the contiguous points. The discordant observation at the time of minimum of λ 4481 (marked as an open circle) is more difficult to account for. The plate is of good quality, and the lines λ 4471 and λ 4481 are both at maximum intensity. It is the only spectrogram obtained at that particular epoch at the phase when magnesium is normally faint. A plate taken at the succeeding epoch shows the

line at a minimum. The cause of the discrepancy cannot be cleared up at the present time.

The estimates of the intensities of the two lines shown in Figure 1 were made at different times so that there could be no subconscious tendency to estimate one line at maximum if the other had been placed at minimum, or the converse. For this reason, the curves for helium and magnesium should be entirely independent of each other

TABLE II

| J.D. | Phase | $H\gamma$ | He I 4387 | He I 4471 | Mg II 4481 | $\left.\begin{matrix}Fe\ II\\Ti\ II\end{matrix}\right\}$ 4549 | He I 4713 |
|---|---|---|---|---|---|---|---|
| 2416586.9..... | 139.1 | 40 | 3 | 11 | 14 | 1 | 2 |
| 2416587.9..... | 140.1 | 25 | 2 | 11 | 11 | 1 | 2 |
| 2416600.9..... | 153.1 | 30 | 2 | 17 | 9 | 1 | 1 |
| 2416601.9..... | 154.1 | 30 | 2 | 17 | 10 | 1 | 2 |
| 2417363.8..... | 15.0 | 30 | 2 | 9 | 18 | 1 | 2 |
| 2417401.7..... | 52.9 | 45 | 3 | 10 | 18 | 2 | 1 |
| 2417412.6..... | 63.8 | 45 | 1 | 9 | 19 | 1 | 1 |
| 2417419.6..... | 70.8 | 35 | 3 | 9 | 19 | 1 | 2 |
| 2417433.6..... | 84.8 | 50 | 3 | 8 | 20 | 1 | 1 |
| 2417443.6..... | 94.8 | 50 | 1 | 9 | 18 | 1 | 1 |
| 2417459.6..... | 110.8 | 35 | 2 | 6 | 9 | 1 | 2 |
| 2417464.6..... | 115.8 | 30 | 2 | 9 | 19 | 3 | 1 |
| 2417475.6..... | 126.8 | 35 | 3 | 12 | 19 | 2 | 1 |
| 2417485.6..... | 136.8 | 40 | 3 | 10 | 17 | 1 | 2 |
| 2417503.5..... | 154.7 | 40 | 3 | 17 | 17 | 1 | 2 |
| 2417679.9..... | 150.9 | 25 | 3 | 15 | 10 | 1 | 2 |
| 2417692.9..... | 163.9 | 40 | 3 | 9 | 15 | 0 | 1 |
| 2417696.9..... | 167.7 | 25 | 2 | 8 | 16 | 1 | 1 |
| 2417706.9..... | 178.1 | 30 | 3 | 10 | 17 | 1 | 1 |

as far as the complementary behavior of the lines at periastron is concerned. The intensities of the lines were determined by comparison with a spectrogram, the intensities of whose lines had been estimated on an arbitrary scale.

The maximum of λ 4471 and the minimum of λ 4481 seem to occur about nine days after periastron, but the curves are not sufficiently well defined to permit certainty.

It should be noted that any apparent variation in the intensity of the lines which might be due to the quality of the plates would tend to make all the lines systematically stronger or fainter. Such an explanation of the variation of the helium and magnesium lines is impossible, since the lines vary in opposite directions.

The hydrogen lines were suspected of varying in intensity, but I was not able to correlate their intensities with the spectroscopic period, and the varying density of the different plates made the estimates rather uncertain. The *Si* II doublet λ 4128 and λ 4131 may vary in phase with *Mg* II 4481, but the plates are too weak in this region to allow a decision to be made.

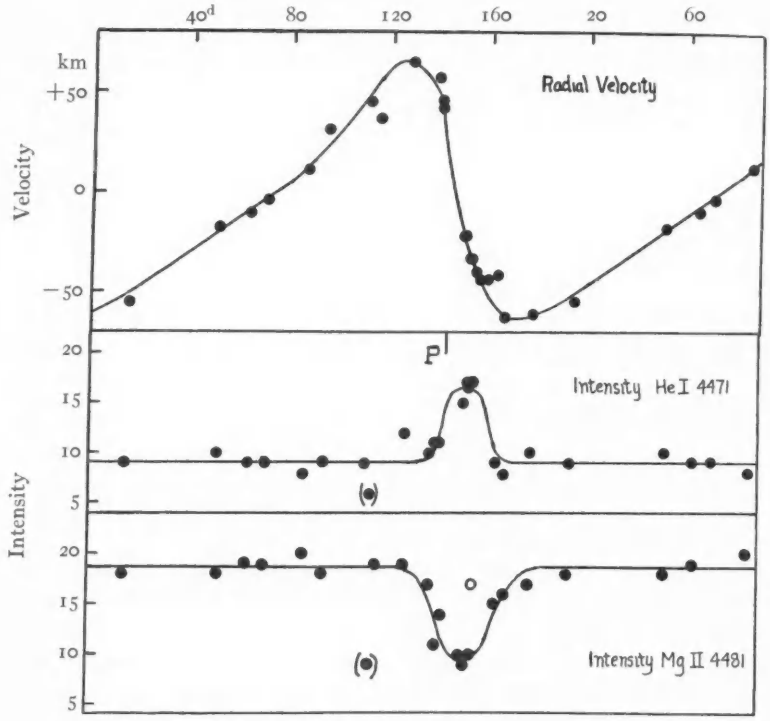


FIG. 1.—Radial velocity-curve and intensities of the variable lines in μ Sagittarii. The position of periastron passage is marked.

The most puzzling feature of the variation of the spectral lines is the difference in the behavior of certain of the helium lines. If the variation in intensity were due to a change in effective excitation, we should expect all the helium lines to behave in the same manner. If the conditions favored higher excitation, the helium lines should be strengthened, as the maximum intensity of *He* I occurs at B3. We should also expect such ions as *Mg* II and *Si* II to be weakened,

as they are past their maxima, but the peculiar behavior of the helium singlets and of the triplets λ 4121 and λ 4713 is difficult to explain. O. Struve has found that the relative intensities of the helium singlets and triplets vary with absolute magnitude on both sides of spectral type B3. As the triplets do not all behave in the same manner in $\mu$ Sagittarii, the effect does not seem to be one of absolute magnitude alone.

The high eccentricity of the orbit of the binary and the fact that the principal star is a supergiant would probably result in a rather close approach of the two stars at periastron, in spite of the rather long period of orbital revolution. In the case of such a close approach it does not seem improbable that there might be changes of some sort in their physical condition due to their effect on each other. If the effect were a cumulative one, the apparent lag in the maxima and minima of the intensities of the variable lines might also be accounted for.

Data concerning physical changes in spectroscopic binaries are very meager. S. I. Bailey found[1] that the lines of the secondary component of the spectroscopic binary $\mu^1$ Scorpii were at certain times nearer in intensity to those of the primary than at others. The spectrum was studied also by Miss A. J. Cannon[2] and by Miss A. C. Maury.[3] Miss Cannon noted that the difference in intensity between the two spectra is greater when the less intense lines have greater wave-length than when they are of shorter wave-length. Miss Maury found that the variation was periodic with apparently irregular fluctuations, and that it was accompanied by changes in the width and distribution of energy of the individual lines. Attention was called to the similarities in the behavior of the spectrum to that of the Cepheid variables. Miss Maury also found that the helium lines λ 4026, λ 4387, and λ 4471, together with $H\gamma$, varied in intensity in phase in the spectrum of the fainter star. Miss Maury found a similar case in the behavior of the spectrum of V Puppis.[4] The spectral lines underwent changes in structure, bright borders being observed on the edges of the absorption lines which were strong at certain times on the red edges and at others on the violet.

[1] *Harvard Circular*, **11**, 1896.

[2] *Harvard Annals*, **28**, Part II, Remark 73.

[3] *Ibid.*, **84**, 157.

[4] *Ibid.*

The relative intensities of the absorption lines in the spectra of the two components were found to vary, as in the case of $\mu^1$ Scorpii, but to a less degree. The lines of each star seemed to become stronger as it approached the earth and weaker as it receded from the earth.

O. Struve and C. T. Elvey found[1] that the absorption lines in 7 $\epsilon$ Aurigae were systematically strengthened at the time of the eclipse of the bright star in 1928–1929. They also suspected variations in the relative intensities of certain lines.

R. N. van Arnam noted[2] that in the case of the spectroscopic binary B.D.$-18^\circ 3295$ the secondary spectrum was measured more often when it was displaced toward the red of the primary than when it was displaced toward the violet. This would suggest the possibility of the secondary spectrum being stronger at maximum than at minimum of its velocity shift.

It would be of interest to test the light of $\mu$ Sagittarii photometrically at the times of periastron and apastron.

I am indebted to Dr. Struve for advice and suggestions during the course of the work.

YERKES OBSERVATORY
WILLIAMS BAY, WIS.
February 22, 1932

[1] *Astrophysical Journal*, **71**, 136, 1930.

[2] *Ibid.* (In press.)

# THE SPECTRUM OF B.D.+11°4673 DURING THE YEARS 1929–1931[1]

By PAUL W. MERRILL

ABSTRACT

*New series of observations.*—Twenty-two single-prism spectrograms taken during 1929–1931 serve as a basis for a further study of this complex Be spectrum.

*Behavior of lines.*—No radical changes in the character of the spectrum occurred during this interval, and the 800-day fluctuations in the intensities and displacements of the lines were repeated approximately as before (see *Mt. Wilson Contr.*, No. 381; *Astrophysical Journal*, **69**, 330, 1929). Detailed data are given concerning the bright and dark lines of *H*, *He*, *Fe* II, *Al* III, *N* II, and *Si* III. Anomalous differences in phase previously found for various elements are confirmed. Certain small deviations from the earlier behavior are noted, including a possible lengthening of the period. The dark lines have continued to move toward shorter wave-lengths.

*Possible relationship to Cepheid variables.*—The question is raised whether the phenomena observed in this spectrum have any relationship to the small discrepancies noted in Cepheid variables between results from various lines.

Previous investigation[2] of the complex spectrum of this peculiar Be star had disclosed so many interesting peculiarities that it appeared worth while to continue the observations through one more cycle of the 800-day period. Spectrograms, listed in Table I, were therefore obtained about once a month throughout the observing seasons of 1929, 1930, and 1931. All were taken on the Eastman 33 emulsion with the one-prism spectrograph and 18-inch camera attached to the 100-inch telescope. The adjustments of the instrument and the observing procedure were similar to those used in the previous investigation; hence the two series of spectrograms are closely comparable.

No radical change in the character of the spectrum occurred during this interval, and the periodic fluctuations in the intensities and displacements of the lines were repeated approximately as before. It will therefore be possible to report the new data briefly by comparison with the previous results. Many of the important features are shown graphically in Figures 1 and 2. The plates are much more numerous than in any previous interval of equal length, and it is

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 450.

[2] P. W. Merrill, *Publications of the Observatory, University of Michigan*, **2**, 71, 1916; also *Mt. Wilson Contr.*, No. 381; *Astrophysical Journal*, **69**, 330, 1929.

interesting that certain anomalous phenomena discovered by combining data from several cycles find confirmation in the present investigation by the direct comparison of observations within a single cycle.

TABLE I

JOURNAL OF OBSERVATIONS AND ESTIMATES OF THE INTENSITIES OF LINES

| PLATE | DATE | J.D. | HYDROGEN | | HELIUM | | IONIZED IRON | |
|---|---|---|---|---|---|---|---|---|
| | | | Em. | Abs. | Em. | Abs. | Lab. | Forb. |
| | | 2420000 | | | | | | |
| C 5190 | 1929 May 22 | +5754 | 12 | 1 | 10 | 6 | 2 | 3 |
| 5226 | June 22 | 5785 | 11 | 2 | 10 | 5 | 1 | 2 |
| 5240 | July 17 | 5810 | 10 | 4 | 9 | 6 | 1 | 1 |
| 5270 | Aug. 17 | 5841 | 11 | 1 | 10 | 5 | 1 | 1 |
| 5307 | Sept. 13 | 5868 | 10 | 2 | 10 | 5 | 0 | 0 |
| 5331 | Oct. 9 | 5894 | 9 | 5 | 9 | 5 | 0 | 0 |
| 5351 | Nov. 20 | 5936 | 8 | 6 | 8 | 6 | 0 | 1 |
| 5369 | Dec. 13 | 5959 | 7 | 8 | 8 | 5 | 1 | 1 |
| 5480 | 1930 June 13 | 6141 | 8 | 6 | 8 | 5 | 2 | 1 |
| 5495 | July 9 | 6167 | 10 | 7 | 9 | 5 | 3 | 4 |
| 5509 | Aug. 6 | 6195 | 10 | 6 | 8 | 5 | 4 | 3 |
| 5546 | Sept. 10 | 6230 | 12 | 3 | 8 | 6 | 5 | 3 |
| 5574 | Oct. 14 | 6264 | 13 | 2 | 9 | 7 | 5 | 2 |
| 5637 | Dec. 3 | 6314 | 12 | 1 | 10 | 6 | 5 | 1 |
| 5727 | 1931 May 8 | 6470 | 11 | 1 | 7 | 5 | 4 | 0 |
| 5739 | May 30 | 6492 | 12 | 0 | 9 | 6 | 4 | 0 |
| 5779 | July 4 | 6527 | 12 | 0 | 10 | 5 | 3 | 1 |
| 5784 | July 6 | 6529 | 12 | 1 | 9 | 6 | 3 | 0 |
| 5797 | July 30 | 6553 | 11 | 1 | 9 | 7 | 2 | 0 |
| 5828 | Aug. 31 | 6585 | 11 | 1 | 9 | 6 | 2 | 0 |
| 5853 | Oct. 1 | 6616 | 12 | 1 | 9 | 5 | 1 | 0 |
| 5875 | Oct. 27 | 6642 | 12 | 1 | 9 | 4 | 1 | 0 |

## HYDROGEN LINES

The estimated intensities of the bright and dark components of the hydrogen lines are in Table I. They were made by a direct comparison on the Hartmann spectrocomparator of each plate with C 2342, the plate used for reference in the former series. As before, the correlation is inverse: relatively weak bright lines are accompanied by strong dark lines, and when the bright lines are strong, the dark borders are scarcely visible (see Fig. 1). A minimum of the intensity of the bright lines and a maximum of that of their dark borders occurred about J.D. 2426020. On the plates of the new series, the bright components are wider and their edges less sharp

than on C 2342, and the decrement of intensity from $H\beta$ to $H\epsilon$ appears to be less, but this may be an instrumental effect.

The distances between the centers of the bright lines and their dark companions are somewhat greater than before, being 1.55 and

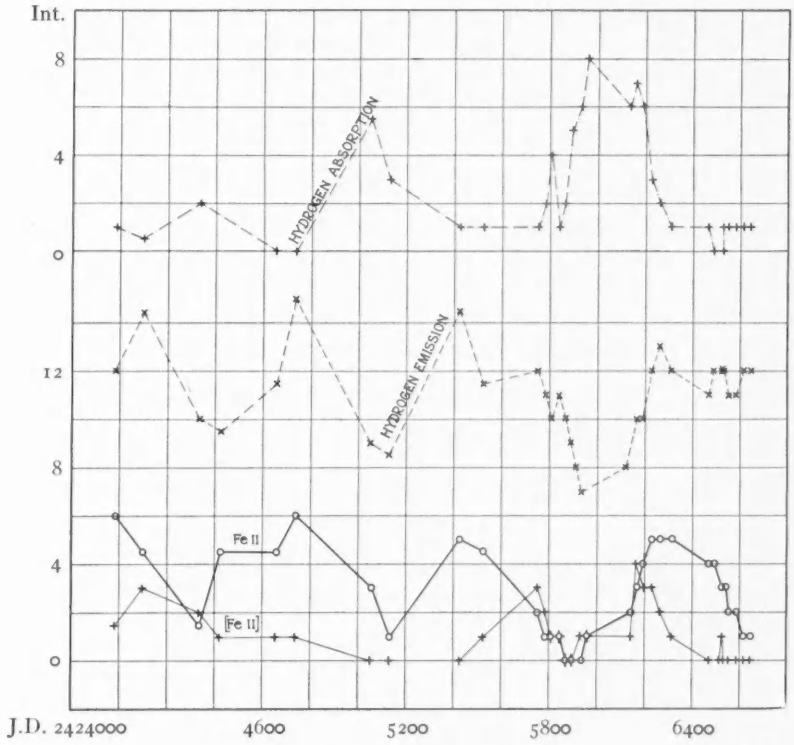


FIG. 1.—Intensities of lines

1.80 A for $H\delta$ and $H\gamma$, respectively. The means for various years are in Table II. The dependence on wave-length is represented approximately by the equation

$$\Delta\lambda = a\lambda^3 ,$$

but $a$ is now 2.2 instead of 1.25 or 1.9, as in earlier years.

The measured displacements of the bright hydrogen lines are in Table III (plotted in Fig. 2). The individual lines agree reasonably well; mean values of the differences in velocity are $H\beta - H\gamma$, +1.9;

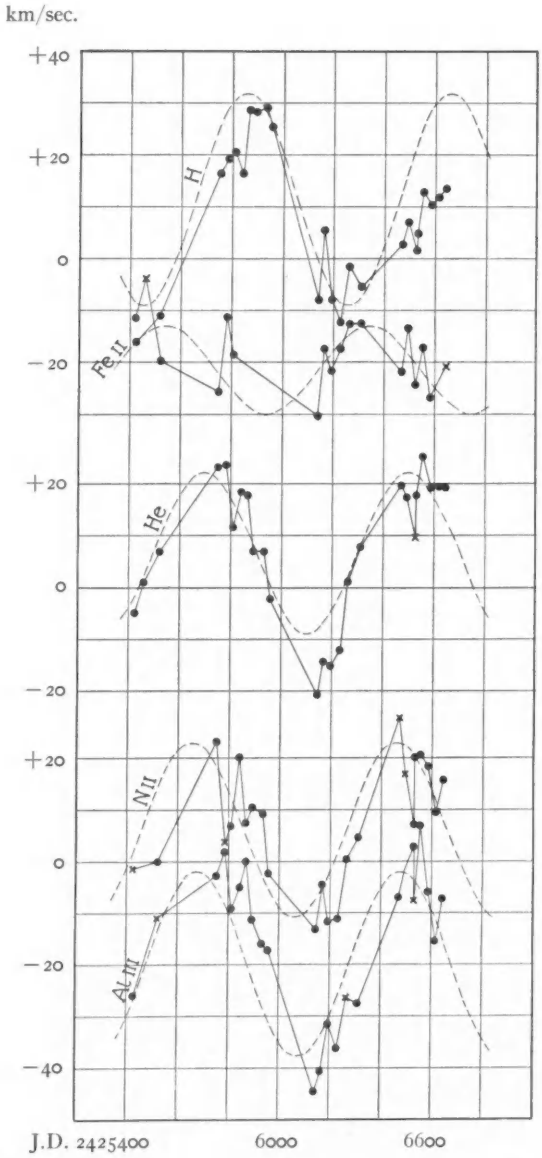


Fig. 2.—Velocities from emission lines. The smooth curves (dash lines) are computed from equations derived in *Contribution* No. 381.

$H\gamma - H\delta, -0.5$; $H\delta - H\epsilon, +0.9$ km/sec. These results are slightly smaller than the means for previous years (Table VII, *Contribution* No. 381). The dotted curve (Fig. 2),

$$V = 20.5 \sin 360^\circ \frac{t - 4860}{800} + 11.5 ,$$

is that computed to represent the previous observations. Near J.D. 2425800, and more especially near J.D. 2426600, the points fall systematically below the curve, thus indicating a definite departure from the behavior of the cycles immediately preceding and perhaps a return to a smaller amplitude (see Fig. 4, *Contribution* No. 381).

TABLE II

HYDROGEN LINES

(Emission *minus* Absorption)

| Year | $H\gamma$ | $H\delta$ | $H\epsilon$ |
|---|---|---|---|
| 1915 | 1.59 A | 1.23 A | 1.26 A |
| 1919 | 0.99 | 0.76 | 0.70 |
| 1920 | 1.01 | 0.93 | ..... |
| 1921 | 1.53 | 1.29 | 1.22 |
| 1923 | 1.66 | 1.33 | 1.15 |
| 1925 | 1.17 | 0.93 | 0.78 |
| 1927 | 1.56 | ..... | ..... |
| 1929 | 1.85 | 1.55 | ..... |
| 1930 | 1.74 | 1.50 | ..... |
| 1931 | ..... | 1.60 | ..... |

HELIUM LINES

Neither the structures nor the intensities of the helium lines have changed greatly during the three-year period, although the wave-length intervals between the centers of the bright lines and their dark borders are somewhat greater than before (Table IV). The variation with wave-length is about as the third power.

The sine-curve previously computed represents fairly well the velocities derived from the helium lines (Fig. 2). It requires, however, a small displacement toward the right, thus indicating a slightly longer period or a shift in phase. The observed minimum falls below the curve. The remarkable difference in phase of 160 days between the curves for hydrogen and for helium (Table XXVI,

*Contribution* No. 381) is clearly shown at the well-determined maxima near J.D. 2425800. This surprising phenomenon is thus confirmed by new observations made within a single cycle.

TABLE III

RADIAL VELOCITIES FROM EMISSION LINES

(Kilometers per Second)

| Plate | *H* | *He* | *N* II | *Al* III | *Fe* II | [*Fe* II] |
|---|---|---|---|---|---|---|
| C 5190 | +16 | +23 | +23 | − 3 | −26 | −15 |
| 5226 | +19 | +24 | (+ 4) | + 2 | −11 | − 7 |
| 5240 | +20 | +12 | + 7 | − 9 | −18 | (− 7) |
| 5270 | +16 | +18 | +20 | − 5 | ..... | ..... |
| 5307 | +29 | +18 | + 7 | 0 | ..... | ..... |
| 5331 | +28 | + 7 | +10 | −11 | ..... | (−35) |
| 5351 | +29 | + 7 | + 9 | −16 | ..... | (−19) |
| 5369 | +25 | − 2 | − 2 | −17 | ..... | (−43) |
| 5480 | − 8 | −21 | −13 | −45 | −30 | ..... |
| 5495 | + 5 | −14 | − 4 | −41 | −17 | −22 |
| 5509 | − 8 | −15 | −12 | −32 | −22 | −36 |
| 5546 | −12 | −12 | −11 | −36 | −17 | −17 |
| 5574 | − 2 | + 1 | 0 | (−26) | −12 | −15 |
| 5637 | − 6 | + 8 | + 5 | −28 | −12 | ..... |
| 5727 | + 3 | +20 | (+28) | − 7 | −22 | ..... |
| 5739 | + 7 | +17 | (+17) | − 2 | −13 | (+ 8) |
| 5779 | + 1 | +10 | + 7 | + 3 | −24 | ..... |
| 5784 | + 5 | +18 | +20 | − 8 | −24 | ..... |
| 5797 | +13 | +25 | +20 | + 7 | −17 | ..... |
| 5828 | +10 | +19 | +18 | − 6 | −27 | ..... |
| 5853 | +12 | +19 | + 9 | −16 | ..... | (−20) |
| 5875 | +14 | +19 | +16 | − 7 | (−21) | ..... |

TABLE IV

HELIUM LINES

| λ | EMISSION *minus* ABSORPTION | | MEAN VELOCITY FROM ABSORPTION LINES 1929–1931 | |
|---|---|---|---|---|
| | 1921–1928 | 1929–1931 | Vel. | No. Obs. |
| 3965 | 1.11 A | 1.22 A | (− 88) km/sec. | 3 |
| 4009 | 1.05 | 1.06 | 79 | 8 |
| 4026 | 1.13 | 1.28 | 83 | 16 |
| 4120 | 0.87 | 1.12 | 78 | 19 |
| 4143 | 1.08 | 1.22 | 82 | 19 |
| 4388 | 1.36 | 1.41 | 87 | 22 |
| 4437 | 1.4 | 1.6 | ( 112) | 5 |
| 4471 | 1.58 | 1.73 | 104 | 22 |
| 4712 | 1.59 | 1.78 | 100 | 21 |
| 4922 | ..... | ..... | −116 | 21 |

The mean velocities derived from the dark components of the various helium lines are in Table IV. They appear to increase with the wave-length, and hence indicate that the measured displacements are not wholly due to radial motion. The mean velocities for individual plates (Table V), taken without regard to the relatively small systematic differences between the lines, yield a curve essen-

TABLE V

APPARENT VELOCITIES FROM DARK LINES

(Kilometers per Second)

| Plate | *He* | *Si* III λλ 4552, 67, 74 | *N* II λ 3995 |
|---|---|---|---|
| C 5190 | − 77 | − 69 | ..... |
| 5226 | 79 | 54 | ..... |
| 5240 | 95 | 113 | ..... |
| 5270 | 80 | 53 | ..... |
| 5307 | 75 | 48 | ..... |
| 5331 | 97 | 61 | − 63 |
| 5351 | 106 | 78 | ..... |
| 5369 | 112 | 112 | 96 |
| 5480 | 126 | 114 | ..... |
| 5495 | 110 | 86 | 85 |
| 5509 | 98 | 88 | ..... |
| 5546 | 95 | 88 | 104 |
| 5574 | 96 | 98 | 101 |
| 5637 | 97 | (83) | ..... |
| 5727 | 78 | 73 | ..... |
| 5739 | 79 | 67 | 63 |
| 5779 | (96) | (88) | 63 |
| 5784 | 82 | 62 | 65 |
| 5797 | 77 | 64 | 64 |
| 5828 | 84 | 62 | ..... |
| 5853 | 72 | 68 | ..... |
| 5875 | − 66 | − 48 | − 58 |

tially similar to that from the bright lines but displaced about 100 km/sec. toward algebraically smaller values. Thus, to a first approximation, bright and dark lines move together in the 800-day fluctuation. It is not certain, however, that both curves have exactly the same shape: the curve for the absorption line, for example, may rise more abruptly after minimum velocity than that from the emission lines.

## IRON LINES

The general resemblance between the changes in the intensities of ionized iron lines and those of hydrogen has been maintained, but

an interesting divergence in behavior occurred toward the end of the series: from J.D. 2426470 to J.D. 2426640 the intensities of iron lines decreased rapidly, while those of hydrogen remained nearly constant. A similar relationship was observed about J.D. 2423100 (Fig. 13, *Contribution* No. 381).

The sine-curve previously computed represents the velocities fairly well. The difference in phase between this curve and that for hydrogen is striking, the maximum velocity for iron occurring only a little after the minimum for hydrogen. This displacement is especially remarkable in view of the general agreement in phase of the changes in intensity in the two elements.

The forbidden iron lines [*Fe* II] are weak on most of the recent plates, but at times their intensities change quite differently from those of the laboratory iron lines (Table I and Fig. 1). The measured displacements of the forbidden lines are somewhat scattering, but they probably agree within errors of measurement with those derived from the laboratory lines.

### ALUMINUM LINES

A line of *Al* III, λ 4529, was measured in emission on all plates, and the weaker companion line λ 4512 on more than half of them. The sine-curve computed to represent the earlier velocities requires a shift toward the right of perhaps 60 days, thus indicating either a period longer than 800 days or a positive displacement of phase. No dark companions were observed.

### NITROGEN LINES

The bright nitrogen lines yield, as before, a displacement-curve very similar to that derived from the bright helium lines. The relative displacements of bright and dark components are somewhat greater than before, as shown by Table VI.

The dark line accompanying λ 3995 has been measured on those plates having sufficient density in this region. It appears to shift with the bright lines. The displacements are in Table V.

### SILICON LINES

Measured displacements of the dark *Si* III lines λλ 4552, 4567, 4574 (Table V) are rather scattering, but indicate a minimum at

approximately the same epoch as that given by *He*, *N* II, *Al* III. The displacements of the dark *Si* III lines behave in general much like those of the dark line of *N* II, λ 3995. On a few plates weak emission was visible on the red edge of the dark lines λλ 4552, 4567. The relative displacements of bright and dark components were 1.6 and 1.9 A, respectively, as compared with 1.3 and 1.4 A in the earlier series.

## CONCLUSIONS

The principal fact brought out by the present investigation is that during the years 1929–1931 the phenomena observed from 1921 to 1928 were repeated with only minor variations.

TABLE VI

*N* II, EMISSION *minus* ABSORPTION

| λ | 1921–1928 | 1929–1931 |
|---|---|---|
| 3995 | 0.89 A | 1.02 A |
| 4601 | 1.59 | 1.61 |
| 4607 | 1.68 | 1.82 |
| 4643 | 2.26 | 2.32 |

No radical changes in the behavior of the intensities of the lines have occurred. The 800-day cycle previously found has continued in the changing intensities of the hydrogen and iron lines. The changes in the helium lines have been relatively small. Little evidence has yet appeared of a tendency to return to the conditions which prevailed prior to 1920.

The periodic fluctuations in the positions of the lines have continued with the remarkable discrepancies between various elements much as before. The curves of *He*, *N* II, *Al* III, and we may now add *Si* III, agree approximately in phase; the curve for hydrogen follows by 150 days,[1] and that for *Fe* II precedes by about 140 days. The maxima and minima of the displacements of iron lines thus precede those of hydrogen by about 290 days. The amplitudes of the curves differ but little from those previously found, except that of hydrogen, which may now be decreasing, possibly having passed through a maximum about 1928. The minimum velocity of helium in 1930

[1] This interval may be slightly less than in previous years.

was lower than before, while the neighboring maxima were of about the same height as usual. The mean velocities ($V_0$) of all the curves are about the same as before.

The velocities, with the possible exception of those derived from iron lines, show a general tendency to occur later than those predicted from the 800-day sine-curves based on the earlier data. Unless merely a peculiarity of the individual cycle, this delay indicates a lengthening period.

TABLE VII

MEAN DISPLACEMENTS OF ABSORPTION LINES

(Kilometers per Second)

| Element | 1915 | 1919–1920 | 1921–1928 | 1929–1931 |
|---|---|---|---|---|
| *He* | −11 | −45 | −85 | −90 |
| *N* II, λ 3995 | + 4 | −37 | −66 | −76 |
| *Si* III, λλ 4552, 4567, 4574 | −13 | −19 | −69 | −76 |

The dark lines have continued their progress toward shorter wavelengths, although recent changes have been slight. The data are summarized in Table VII. It is noteworthy that the dark silicon lines give nearly as large displacements as the dark helium lines, although the bright silicon components are so weak that they were measured on very few plates, while the bright helium lines are well developed.

In conclusion, the following question may be raised: Are the differences between the displacement-curves for various elements in B.D.+11°4673 comparable in origin or general nature with the much smaller differences reported by other observers in the behavior of various lines in Cepheid variables? If so, we should expect to find the Cepheid lines showing differences in phase and amplitude, and possibly in the velocity of center of mass.

CARNEGIE INSTITUTION OF WASHINGTON
MOUNT WILSON OBSERVATORY
January 1932

# MINOR CONTRIBUTIONS AND NOTES

## NOTE ON THE SPECTRUM OF 37 $\theta$ AURIGAE

ABSTRACT

A number of lines in the spectrum of 37 $\theta$ Aurigae have been found to vary in intensity. Most of the variable lines are due to *Cr* II. With respect to the variation of the chromium lines the star is similar to B.D.-18°3789.

The spectrum of the star 37 $\theta$ Aurigae (position 1900: $\alpha = 5^h 52^m.9$, $\delta = +37°12'$; vis. mag., 2.71) is given as A0p by the *Henry Draper Catalogue*. The spectrum was classed as peculiar because of the strength of the *Si* II doublet, λλ 4128 and 4131, the weakness of *Ca* I, K, and because of similarities to the peculiar star $\alpha^2$ Canum Venaticorum.

TABLE I

VARIABLE LINES IN $\theta$ AURIGAE

| λ | Intensity September 22, 1930 | Intensity October 19, 1930 | Identification |
|---|---|---|---|
| 4049.0 | 2–3 | 6 | ..... |
| 4077.7 | 2–3 | 6 | *Sr* II .72 |
| 4111.2 | 1–2 | 6 | *Cr* II .09 |
| 4132.3 | 0 | 4 | ..... |
| 4215.7 | 3 | 6 | *Sr* II .52 |
| 4252.4 | 1–2 | 5 | *Cr* II .65 |
| 4254.4 | 1 | 4 | *Cr* I .35 |
| 4269.1 | 2 | 5 | *Cr* II .30 |
| 4558.8 | 4 | 8 | *Cr* II .66 |

Two spectrograms of $\theta$ Aurigae taken on September 22 and October 19, 1930, show changes in the intensities of certain absorption lines. The plates were obtained with the Bruce spectrograph attached to the 40-inch telescope. The spectrograms were taken on the fine-grained Eastman process emulsion and are of very good quality. A total of nine lines are listed in Table I as being systematically fainter on September 22 than on October 19. The wave-lengths given in the first column were obtained by comparison with a spectrogram of 73 Draconis. The intensities of the lines listed in the second and third columns are on a scale in which the faintest line discernible is of

intensity 1, while the very strong silicon doublet is estimated 15. Five of the nine lines are well-known laboratory lines of *Cr* II; one is the ultimate line of *Cr* I, and it is possible that the variation in most of the other lines can be ascribed to fainter predicted *Cr* II lines. It does not seem wise to decide definitely as to the identification of all the lines until a complete study of the spectrum can be made.

It should be noted that the variable lines observed in $\theta$ Aurigae are among the strongest of the chromium group of variable lines in B.D.-18°3789 on which I reported in this *Journal*.[1] The range of variation is greater, however, in the latter star. Photo-electric observations of $\theta$ Aurigae by J. Stebbins[2] do not show any measurable variation in brightness.

It is probable that a number of other lines vary in intensity in $\theta$ Aurigae, but it will be necessary to obtain more plates before a complete study of the star can be made. The star has been put back on the observing program and a series of plates for a complete study will be obtained.

W. W. Morgan

Yerkes Observatory
Williams Bay, Wis.
January 28, 1932

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## DETECTION OF THE GEGENSCHEIN WITH A PHOTO-ELECTRIC PHOTOMETER

ABSTRACT

Observations of the brightness of the sky with the photo-electric photometer of the Yerkes Observatory across the region of the Gegenschein show its presence, and also show the possibility of a detailed study of it.

Some preliminary observations have been made with the photo-electric photometer attached to the 40-inch telescope of the Yerkes Observatory to determine the feasibility of studying the Gegenschein. The photometer has been described by Joel Stebbins.[3] The large scale of the 40-inch telescope was advantageous since regions of the sky free from stars could be chosen for measurement. The

[1] *Astrophysical Journal*, **74**, 24, 1931.

[2] *Publications of the Washburn Observatory*, **15**, Part I, 74, 1928.

[3] *Astrophysical Journal*, **74**, 289, 1931.

results are shown in Figure 1. Curve *A* shows the observations taken on March 26, 1932, when the position of the Gegenschein was near

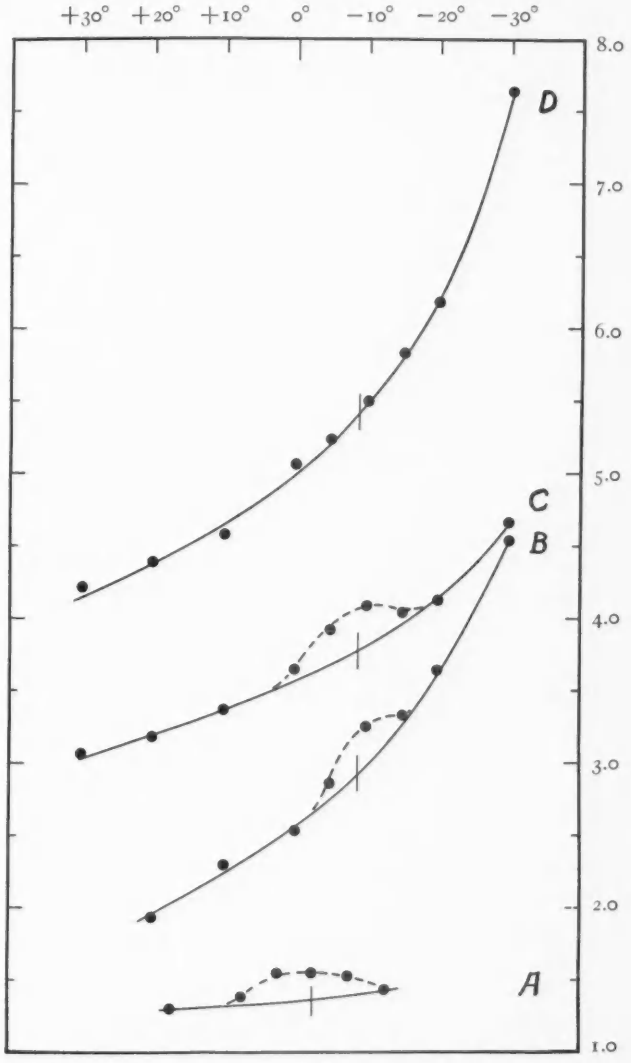


FIG. 1.—Photo-electric observations of the brightness of the sky, showing the Gegenschein. The curves are explained in the text.

$12^h20^m$ and $-2.5°$. The observations were made at the same right ascension but at successively different declinations. The ordinates

in the figure are millivolts per second, the rate of charging of the electrometer. Further observations could not be obtained until the night of April 12, 1932, when the six-day-old moon was above the horizon. The position of the Gegenschein on this date was about $13^h20^m$ and $-9°$. A series of observations was taken first at R.A. $12^h20^m$; the results are shown by curve *D*. Then two series were taken at the right ascension corresponding to that of the Gegenschein, first with decreasing and then with increasing declinations. These are shown by curves *C* and *B*, respectively. The continuous lines give the change of the brightness of the sky with declination, and hence with altitude, which is of course quite pronounced with the moon above the horizon. The decrease in the light of the sky from curve to curve is due to the setting of the moon, which was very near the horizon at the last observation. The declinations corresponding to that of the Gegenschein are marked on each curve with a vertical line. It is seen that the deviations from the smooth curve representing the brightness of the sky have their centers near these declinations. The Gegenschein is shown to extend over about 20° of declination. It might be noted, also, that the curve taken on April 12 at a position one hour west of the position of the Gegenschein is the right ascension of the observations made on March 26.

A preliminary series of observations with filters having effective wave-lengths of $\lambda$ 4750 and $\lambda$ 4250 indicate that the color of the Gegenschein is slightly yellower than that of the background of the sky.

Since the Gegenschein is moving south rapidly and also into the Milky Way, a detailed study of it with the photo-electric photometer will have to be postponed until next fall.

C. T. Elvey

Yerkes Observatory
April 19, 1932

## ERRATA

Vol. 73, No. 3, April, 1931, "The Yerkes Actinometry, Second Series, Zone $+75°$ to $+60°$," by ARTHUR S. FAIRLEY:

| | | | |
|---|---|---|---|
| Page 133 | Star B.D. 68 26 *for* | 7.46 *read* | 8.46 |
| 134 | 63 105 | Mb | Fo |
| 140 | 67 221 | 7.37 | 8.37 |
| 142 | 67 246 | 8.19 | 8.41 |
| 148 | 68 412 | 8.12 | 7.09 |
| 152 | 74 370 | 8.10 | 7.10 |
| 154 | 69 531 | 7.97 | 6.97 |
| 155 | 72 515 | 8.31 | 7.34 |
| 161 | 66 887 | 7.11 | 6.11 |
| 161 | 72 671 | 7.28 | 8.28 |
| 162 | 67 912 | 7.29 | 8.29 |
| 174 | 72 984 | A2 | F8 |
| 177 | 67 1409 | 6.79 | 8.20 |

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Vol. 74, No. 4, November, 1931, "A Study of the Spectra of B Stars," by OTTO STRUVE:

Page 225, line 19 of Abstract: *for* Fowler series *read* Pickering series
Page 237: *for* line 4921.96 *He* III *read He* I
Page 256, line 15 from top: *for* Fowler lines *read* Pickering lines

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Vol. 75, No. 3, April, 1932, "On the Interpretation of the Emission Lines in Stars of Early Spectra Class," by O. STRUVE and P. SWINGS:

Page 169: The formula at the top of the page should read:

$$\frac{r(Mg\ \text{II})}{r(H)} = \left(\frac{2.7}{5.7}\right)^2 = 0.2\,.$$

# INDEX TO VOLUME LXXV

## SUBJECTS


PAGE

Aberration and Red Shift, Stellar. *G. Van Biesbroeck* . . . . . 64

Absolute Magnitudes among Stars Brighter than the Sixth Apparent Magnitude, The Distribution of. *Gustaf Strömberg* . . . . . 115

Absorption Lines, On the Contours of Narrow. *Albrecht Unsöld* . . 106

Atmospheres, Mean Ionization in Stellar. *Henry Norris Russell* . . 337

Atomic Lines in the Sun-Spot Spectrum, Some Results from a Study of the *Charlotte E. Moore* . . . . . 222, 298

37 $\theta$ Aurigae, Note on the Spectrum of. *W. W. Morgan* . . . . . 423

B Stars, Evidence for Space Reddening from Bright. *Emma T. R. Williams* 386

Binary Stars, The Evolution of. *William Markowitz* . . . . . 69

Canal Rays of Uniform Energies, Doppler Effects in Hydrogen. *H. F. Batho and A. J. Dempster* . . . . . 34

27 Canis Majoris, A Note on the Mass of. *Dean B. McLaughlin* . . 60

27 Canis Majoris, Note on. *Otto Struve* . . . . . 158

12 $\alpha^2$ Canum Venaticorum, Variations of Radial Velocity and of Intensity of Spectral Lines in. *Goldena Farnsworth* . . . . . 364

Cepheus, Photo-electric Colors of Stars of Early Type in. *C. T. Elvey and T. G. Mehlin* . . . . . 354

Cerium, The Spectrum of Doubly Ionized. *Arthur S. King and Robert B. King* . . . . . 40

Chromospheric Spectrum outside of Eclipse, Photometry of $H\beta$ in the. *Philip C. Keenan* . . . . . 277

Colors of Stars of Early Type in Cepheus, Photo-electric. *C. T. Elvey and T. G. Mehlin* . . . . . 354

Contours of Narrow Absorption Lines, On the. *Albrecht Unsöld* . . 106

Corona, The Spectrum of the. *S. A. Mitchell* . . . . . 1

Emission Lines in Stars of Early Spectral Class, On the Interpretation of the. *O. Struve and P. Swings* . . . . . 161

Energy-Distribution of the High-Current Vacuum Tube, Spectral. *J. A. Anderson* . . . . . 394

Errata . . . . . 427

Europium in A-Type Stars, Studies in Peculiar Stellar Spectra. III. On the Occurrence of. *W. W. Morgan* . . . . . 46

Evolution of Binary Stars, The. *William Markowitz* . . . . . 69

Gegenschein with a Photo-electric Photometer, Detection of the. *C. T. Elvey* . . . . . 424

PAGE

*Hβ* in the Chromospheric Spectrum outside of Eclipse, Photometry of. *Philip C. Keenan* . . . . . 277
Helium and Magnesium in the Spectrum of 13 μ Sagittarii, On the Variable Lines of. *W. W. Morgan* . . . . . 407
SX Herculis, Spectroscopic Observations of. *Alfred H. Joy* . . . . 127
Hydrogen Canal Rays of Uniform Energies, Doppler Effects in. *H. F. Batho and A. J. Dempster* . . . . . 34
Index . . . . . 428
Ionization in Stellar Atmospheres, Mean. *Henry Norris Russell* . . 337
Iron Star XX Ophiuchi, Spectrum of the. *Paul W. Merrill* . . . . 133
Jupiter, On the Absorption Band at λ6191 in the Spectrum of. *C. T. Elvey and A. S. Fairley* . . . . . 373
Magnesium in the Spectrum of 13 μ Sagittarii, On the Variable Lines of Helium and. *W. W. Morgan* . . . . . 407
Magnitudes among Stars Brighter than the Sixth Apparent Magnitude, The Distribution of Absolute. *Gustaf Strömberg* . . . . . 115
Mass of 27 Canis Majoris, A Note on the. *Dean B. McLaughlin* . . 60
XX Ophiuchi, Spectrum of the Iron Star. *Paul W. Merrill* . . . . 133
Y Ophiuchi, A Spectrophotometric Study of. *C. J. Krieger* . . . . 147
Radial Velocity and of Intensity of Spectral Lines in 12 $\alpha^2$ Canum Venaticorum, Variations of. *Goldena Farnsworth* . . . . . 364
Reviews:
Anderson, John S. (ed.) *Photo-electric Cells and Their Applications* (C. T. Elvey) . . . . . 274
Berliner and Scheel (eds.). *Physikalisches Handwörterbuch* (O. Struve) 372
Delporte, E. *Atlas céleste* (P. C. Keenan) . . . . . 68
Delporte, E. *Délimitation scientifique des constellations (tables et cartes)* (P. C. Keenan) . . . . . 68
Moulton, F. R. *Astronomy* (Otto Struve) . . . . . 66
Permanent International Committee. *Annual Tables of Constants and Numerical Data* (E. B. Frost) . . . . . 371
Permanent International Committee. *Données numériques de spectroscopie* (E. B. Frost) . . . . . 371
Rheden, J. *Photographische Sternkarten (Wolf-Palisa Karten)* (P. C. Keenan) . . . . . 68
St. John, C. E., and Associates. *Revision of Rowland's Preliminary Table of Solar Spectrum Wave-Lengths with an Extension to the Present Limit of the Infra-Red* (P. C. Keenan) . . . . . 274
Rhenium Appearing in the Spectrum of the Electric Furnace, Lines of Tungsten and. *Arthur S. King* . . . . . 379
Solar Radiation. Measurements of Ultra-violet. *Edison Pettit* . . . . 185
Space Reddening from Bright B Stars, Evidence for. *Emma T. R. Williams* 386
Spectral Class, On the Interpretation of the Emission Lines in Stars of Early. *O. Struve and P. Swings* . . . . . 161

PAGE

Spectral Energy-Distribution of the High-Current Vacuum Tube. *J. A. Anderson* . . . . . 394
Spectrophotometric Study of Y Ophiuchi, A. *C. J. Krieger* . . . . 147
Spectrum, Some Results from a Study of the Atomic Lines in the Sun-Spot. *Charlotte E. Moore* . . . . . 222, 298
Spectrum of 37 $\theta$ Aurigae, Note on the. *W. W. Morgan* . . . . . 423
Spectrum of B.D.+11°4673 during the Years 1929–1931, The. *Paul W. Merrill* . . . . . 413
Spectrum of the Corona, The. *S. A. Mitchell* . . . . . 1
Spectrum of Doubly Ionized Cerium, The. *Arthur S. King and Robert B. King* . . . . . 40
Spectrum outside of Eclipse, Photometry of $H\beta$ in the Chromospheric *Philip C. Keenan* . . . . . 277
Spectrum of the Electric Furnace, Lines of Tungsten and Rhenium Appearing in the. *Arthur S. King* . . . . . 379
Spectrum of Jupiter, On the Absorption Band at $\lambda$6191 in the. *C. T. Elvey and A. S. Fairley* . . . . . 373
Spectrum of 13 $\mu$ Sagittarii, On the Variable Lines of Helium and Magnesium in the. *W. W. Morgan* . . . . . 407
Stellar Atmospheres, Mean Ionization in. *Henry Norris Russell* . . 337
Stellar Spectra. III. On the Occurrence of Europium in A-Type Stars, Studies in Peculiar. *W. W. Morgan* . . . . . 46
Sun-Spot Spectrum, Some Results from a Study of the Atomic Lines in the. *Charlotte E. Moore* . . . . . 222, 298
Tungsten and Rhenium Appearing in the Spectrum of the Electric Furnace, Lines of. *Arthur S. King* . . . . . 379
Ultra-violet Solar Radiation, Measurements of. *Edison Pettit* . . . 185
Vacuum Tube, Spectral Energy-Distribution of the High-Current. *J. A. Anderson* . . . . . 394
Variable Lines of Helium and Magnesium in the Spectrum of 13 $\mu$ Sagittarii, On the. *W. W. Morgan* . . . . . 407

# INDEX TO VOLUME LXXV

## AUTHORS


PAGE

ANDERSON, J. A. Spectral Energy-Distribution of the High-Current Vacuum Tube . . . . . 394

BATHO, H. F., and A. J. DEMPSTER. Doppler Effects in Hydrogen Canal Rays of Uniform Energies . . . . . 34

DEMPSTER, A. J., and H. F. BATHO. Doppler Effects in Hydrogen Canal Rays of Uniform Energies . . . . . 34

ELVEY, C. T. Detection of the Gegenschein with a Photo-electric Photometer . . . . . 424

ELVEY, C. T. Review of: Photo-electric Cells and Their Applications. John S. Anderson . . . . . 274

ELVEY, C. T., and A. S. FAIRLEY. On the Absorption Band at λ 6191 in the Spectrum of Jupiter . . . . . 373

ELVEY, C. T., and T. G. MEHLIN. Photo-electric Colors of Stars of Early Type in Cepheus . . . . . 354

FAIRLEY, A. S., and C. T. ELVEY. On the Absorption Band at λ 6191 in the Spectrum of Jupiter. . . . . 373

FARNSWORTH, GOLDENA. Variations of Radial Velocity and of Intensity of Spectral Lines in 12 $a^2$ Canum Venaticorum . . . . . 364

Frost, E. B. Review of: *Annual Tables of Constants and Numerical Data*, Permanent International Committee . . . . . 371

FROST, E. B. Review of: *Données numérique de spectroscopie*, Permanent International Committee . . . . . 371

FROST, E. B. Review of: *Johannes Kepler Festschrift, Teil I*, Dr. Karl Stöckl . . . . . 275

JOY, ALFRED H. Spectroscopic Observations of SX Herculis . . . . 127

KEENAN, PHILIP C. Photometry of $H\beta$ in the Chromospheric Spectrum outside of Eclipse . . . . . 277

KEENAN, P. C. Reviews of: *Délimitation scientifique des constellations (tables and cartes)* and *Atlas céleste*, E. Delporte . . . . . 68

KEENAN, P. C. Review of: *Photographische Sternkarten (Wolf-Palisa Karten)*, J. Rheden . . . . . 68

KEENAN, P. C. Review of: *Revision of Rowland's Preliminary Table of Solar Spectrum Wave-Lengths with an Extension to the Present Limit of the Infra-Red*, C. E. St. John and Associates . . . . . 274

KING, ARTHUR S. Lines of Tungsten and Rhenium Appearing in the Spectrum of the Electric Furnace . . . . . 379

PAGE

KING, ARTHUR S., and ROBERT B. KING. The Spectrum of Doubly Ionized Cerium . . . . . 40
KRIEGER, C. J. A Spectrophotometric Study of Y Ophiuchi . . . . 147
MARKOWITZ, WILLIAM. The Evolution of Binary Stars . . . . . 69
MEHLIN, T. G., and C. T. ELVEY. Photo-electric Colors of Stars of Early Type in Cepheus . . . . . 354
MERRILL, PAUL W. The Spectrum of B.D.+11°4673 during the Years 1929–1931 . . . . . 413
MERRILL, PAUL W. Spectrum of the Iron Star XX Ophiuchi . . . . 133
MITCHELL, S. A. The Spectrum of the Corona . . . . . 1
MORGAN, W. W. Note on the Spectrum of 37 $\theta$ Aurigae . . . . . 423
MORGAN, W. W. On the Variable Lines of Helium and Magnesium in the Spectrum of 13 $\mu$ Sagittarii . . . . . 407
PETTIT, EDISON. Measurements of Ultra-violet Solar Radiation . . 185
RUSSELL, HENRY NORRIS. Mean Ionization in Stellar Atmospheres . 337
STRÖMBERG, GUSTAF. The Distribution of Absolute Magnitudes among Stars Brighter than the Sixth Apparent Magnitude . . . . . 115
STRUVE, OTTO. Note on 27 Canis Majoris . . . . . 158
STRUVE, OTTO. Review of: *Astronomy*, F. R. Moulton . . . . . 66
STRUVE, O. Review of: *Physikalisches Handwörterbuch*, Berliner and Scheel (eds.) . . . . . 372
STRUVE, O., and P. SWINGS. On the Interpretation of the Emission Lines in Stars of Early Spectral Class . . . . . 161
SWINGS, P., and O. STRUVE. On the Interpretation of the Emission Lines in Stars of Early Spectral Class . . . . . 161
UNSÖLD, ALBRECHT. On the Contours of Narrow Absorption Lines . 106
VAN ARNAM, RALPH N. The Spectroscopic Binary B.D.−18°3295 . . 348
VAN BIESBROECK, G. Stellar Aberration and Red Shift . . . . . 64
WILLIAMS, EMMA T. R. Evidence for Space Reddening from Bright B Stars . . . . . 386

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